DEMONSTRATION OF A FULL-SCALE RETROFIT OF THE ADVANCED HYBRID PARTICULATE COLLECTOR TECHNOLOGY

TECHNICAL PROGRESS REPORT

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ABSTRACT

The Advanced Hybrid Particulate Collector (AHPC), developed in cooperation between W.L. Gore & Associates and the Energy & Environmental Research Center (EERC), is an innovative approach to removing particulates from power plant flue gas. The AHPC combines the elements of a traditional baghouse and electrostatic precipitator (ESP) into one device to achieve increased particulate collection efficiency. As part of the Power Plant Improvement Initiative (PPII), this project is being demonstrated under joint sponsorship from the U.S. Department of Energy and Otter Tail Power Company. The EERC is the patent holder for the technology, and W.L. Gore & Associates is the exclusive licensee.

The project objective is to demonstrate the improved particulate collection efficiency obtained by a full-scale retrofit of the AHPC to an existing electrostatic precipitator. The full-scale retrofit is installed on an electric power plant burning Powder River Basin (PRB) coal, Otter Tail Power Company's Big Stone Plant, in Big Stone City, South Dakota. The $13.4 million project was installed in October 2002. Project related testing will conclude in November 2004.

The following Technical Progress Report has been prepared for the project entitled "Demonstration of a Full-Scale Retrofit of the Advanced Hybrid Particulate Collector Technology" as described in DOE Award No. DE-FC26-02NT41420. The report presents the operation and performance results of the system.

POINT OF CONTACT

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LIST OF ACRONYMS

A/C	air-to-cloth ratio
AG	(Swiss, translation roughly is Incorporation or consolidation)
AHPC	advanced hybrid particulate collector
APS	aerodynamic particle sizer
COHPAC	compact hybrid particulate collector
CPC	condensation particle counter
DOE	U.S. Department of Energy
EERC	Energy & Environmental Research Center
EPA	U.S. Environmental Protection Agency
ePTFE	expanded polytetrafluoroethylene
ESP	electrostatic precipitator
FF	fabric filter
HEPA	high-efficiency particulate air
HiPPS	high-performance power system
MWh	megawatt hours
μm	micrometer
NSPS	New Source Performance Standards
O&M	operating and maintenance
OEMs	original equipment manufacturers
OTP	Otter Tail Power Company
P&ID	Piping and Intrumentation Diagram
PID	Proportional-Integral-Derivative
PJBH	pulse-jet baghouse
PM	particulate matter
PPS	polyphenylene sulfide
PRB	Powder River Basin
PJFF	pulse-jet fabric filter
P-84	aromatic polyimide
QAPP	quality assurance project plan
RGFF	reverse-gas fabric filter
SCA	specific collection area
SMPS	scanning mobility particle sizer
TR	transformer-rectifier
UND	University of North Dakota
W.C.	water column

EXECUTIVE SUMMARY

This document summarizes the operational results of a project titled "Demonstration of a Full-Scale Retrofit of the Advanced Hybrid Particulate Collector Technology". The Department of Energy's National Energy Technology Laboratory awarded this project under the Power Plant Improvement Initiative Program.

The advanced hybrid particulate collector (AHPC) was developed with funding from the U.S. Department of Energy (DOE). The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in novel manner. The AHPC combines fabric filtration and electrostatic precipitation in the same housing, providing major synergism between the two methods, both in particulate collection and in transfer of dust to the hopper. The AHPC provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emissions with conventional ESPs, and solves the problem of reentrainment and recollection of dust in conventional baghouses.

Big Stone Power Plant operated a 2.5 MWe slipstream AHPC (9000 scfm) for 1½ years. The AHPC demonstrated ultrahigh particulate collection efficiency for submicron particles and total particulate mass. Collection efficiency was proven to exceed 99.9% by one to two orders of magnitude over the entire range of particles from 0.01 to 50 µm. This level of control is well below any current particulate emission standards. These results were achieved while operating at significantly higher air-to-cloth ratios (up to 12 ft/min compared to 4 ft/min) than standard pulse-jet baghouses. To achieve 99.99% control of total particulate and meet possible stricter fine-particle standards, the AHPC is being demonstrated as the possible economic choice over either ESPs or baghouses.

Otter Tail Power Company and its partners, Montana-Dakota Utilities and NorthWestern Energy, installed the AHPC technology into an existing ESP structure at the Big Stone Power Plant. The overall goal of the project is to demonstrate the AHPC concept in a full-scale application. Specific objectives are to demonstrate 99.99% collection of all particles in the 0.01 to 50 µm size range, low pressure drop, overall reliability of the technology and long-term bag life.

The Advanced Hybrid system was installed on the Big Stone Power Plant and put into service on October 25, 2002, at 17:37. The system was installed into an existing Wheelebrator ESP casing during a 5.5-week outage.

Initial startup results were uneventful. This required dedicated effort by the startup personnel from ELEX AG, W.L. Gore and Associates, Southern Environmental Inc. and Otter Tail Power Company. The system was brought up in a steady and controlled manner.

There are two aspects to review during this first quarter of operation, the operation of the mechanical system and the overall system performance.

The mechanical system has operated fairly well. However, there are issues concerning pulse valves, plate rappers, and air flow limitations.

Operationally, the system has shown good environmental performance. Opacity is very low and particulate removal is high. Stack testing by the EERC has shown greater than 99.99% collection efficiency. The complete report can be found in Appendix B24.

The system has negatively affected Plant performance. The differential pressure across the system and the compressed air flow to clean the bags have been higher than expected. The target differential pressure across the tubesheet was 8.0 INH2O. This differential pressure has exceeded 9.5 INH2O. At the current air-to-cloth ratios (10 – 11 fpm), this is of great concern as the projected air-to-cloth ratios will be higher in the summer time as the ambient temperature rises. Overall, other than particulate capture, AHPC system performance is marginal and a deeper understanding of the issues that affect this must be developed. Future efforts include resolving mechanical issues and understanding the fundamental performance parameters of the AHPC technology.

PROJECT NOMENCLATURE DISCUSSION

When this technology was originally developed, the device was referred to as the "Advanced Hybrid Particulate Collector". Since the original development, from concept to an attempt at a commercial demonstration, the name of the technology has changed to "Advanced Hybrid^{TM}". This name was trademarked by W.L. Gore and Associates, Inc. to aid in the commercialization effort and tries to maintain the continuity of the successful history to date. Either "Advanced Hybrid Particulate Collector" (AHPC) or "Advanced Hybrid^{TM}" refers to the same process and equipment.

1.0 INTRODUCTION

The *Advanced Hybrid*™ filter combines the best features of ESPs and baghouses in a unique approach to develop a compact but highly efficient system. Filtration and electrostatics are employed in the same housing, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The *Advanced Hybrid*™ filter provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emissions with conventional ESPs, and solves the problem of reentrainment and re-collection of dust in conventional baghouses.

The goals for the *Advanced Hybrid*™ filter are as follows: > 99.99% particulate collection efficiency for particle sizes ranging from 0.01 to 50 μm, applicable for use with all U.S. coals, and cost savings compared to existing technologies.

The electrostatic and filtration zones are oriented to maximize fine-particle collection and minimize pressure drop. Ultrahigh fine-particle collection is achieved by removing over 90% of the dust before it reaches the fabric and using a GORE-TEX® membrane fabric to collect the particles that reach the filtration surface. Charge on the particles also enhances collection and minimizes pressure drop, since charged particles tend to form a more porous dust cake. The goal is to employ only enough ESP plate area to precollect approximately 90% of the dust. ESP models predict that 90%–95% collection efficiency can be achieved with full-scale precipitators with a specific collection area (SCA) of less than 100 ft^2/kacfm (1, 2). FF models predict that face velocities greater than 12 ft/min are possible if some of the dust is precollected and the bags can be adequately cleaned. The challenge is to operate at high A/C ratios (8–14 ft/min) for economic benefits while achieving ultrahigh collection efficiency and controlling pressure drop. The combination of GORE-TEX® membrane filter media (or similar membrane filters from other manufacturers), small SCA, high A/C ratio, and unique geometry meets this challenge.

Studies have shown that FF collection efficiency is likely to deteriorate significantly when the face velocity is increased (3, 4). For high collection efficiency, the pores in the filter media must be effectively bridged (assuming they are larger than the average particle size). With conventional fabrics at low A/C ratios, the residual dust cake serves as part of the collection media, but at high A/C ratios, only a very light residual dust cake is acceptable, so the cake cannot be relied on to achieve high collection efficiency. The solution is to employ a sophisticated fabric that can ensure ultrahigh collection efficiency and endure frequent high-energy cleaning. In addition, the fabric should be reliable under the most severe chemical environment likely to be encountered (such as high SO_3).

Assuming that low particulate emissions can be maintained through the use of advanced filter materials and that 90% of the dust is precollected, operation at face velocities in the range of 8–14 ft/min should be possible, as long as the dust can be effectively removed from the bags and transferred to the hopper without significant redispersion and re-collection. With pulse-jet cleaning, heavy residual dust cakes are not typically a problem because of the fairly high cleaning energy that can be employed. However, the high cleaning energy can lead to significant redispersion of the dust and subsequent re-collection on the bags. The combination of a very high-energy pulse and a very light dust cake tends to make the problem of redispersion much worse. The barrier that limits operation at high A/C ratios is not so much the dislodging of dust from the bags as it is the transferring of the dislodged dust to the hopper. The *Advanced Hybrid*™ filter achieves enhanced bag cleaning by employing electrostatic effects to precollect a significant portion of the dust and by trapping in the electrostatic zone the redispersed dust that comes off the bags following pulsing.

1.1 History of Development

The *Advanced Hybrid*™ filter concept was first proposed to DOE in September 1994 in response to a major solicitation addressing air toxics. DOE has been the primary funder of the *Advanced Hybrid*™ filter development since that time, along with significant cost-sharing from industrial cosponsors. Details of all of the results have been reported in DOE quarterly technical reports, final technical reports for completed phases, and numerous conference papers. A chronology of the significant development steps for the *Advanced Hybrid*™ filter is shown below.

- September 1994 - *Advanced Hybrid*™ filter concept proposed to DOE
- October 1995 - September 1997 - Phase I - *Advanced Hybrid*™ filter successfully demonstrated at 0.06-MW (200-acfm) scale
- March 1998 - February 2000 - Phase II - *Advanced Hybrid*™ filter successfully demonstrated at 2.5-MW (9000-acfm) scale at Big Stone Plant
- September 1999 - August 2001 - Phase III - *Advanced Hybrid*™ filter commercial components tested and proven at 2.5-MW scale at Big Stone Plant
- Summer 2000 – Minor electrical damage on bags first observed
- January–June 2001 – To prevent electrical damage, the *Advanced Hybrid*™ filter perforated plate configuration was developed, tested, and proven to be superior to the original design
- July 2001 - December 2004 - Mercury Control with the *Advanced Hybrid*™ Filter - Extensive additional testing of the perforated plate concept was conducted with the 2.5-MW pilot unit

1.2 Design of the Perforated Plate *Advanced Hybrid*™ Filter Configuration

After bag damage was observed in summer 2000, extensive experiments were carried out at an Energy & Environmental Research Center (EERC) laboratory to investigate the interactions between electrostatics and bags under different operating conditions. The 200-acfm *Advanced Hybrid*™ filter was first operated without fly ash under cold-flow conditions with air. The effects of electrode type, bag type, plate-to-plate spacing, the relative distance from the electrodes to plates compared to the distance from the electrodes to the bags (spacing ratio), and various grounded grids placed between the electrodes and bags were all evaluated. Several of the conditions from the cold-flow tests were selected and further evaluated in hot-flow coal combustion tests. While all of these tests resulted in very low current to the bags, there appeared to be a compromise in overall *Advanced Hybrid*™ filter performance for some configurations.

A configuration that appeared to have promise was a perforated plate design in which a grounded perforated plate was installed between the discharge electrodes and the bags to protect the bags. On the opposite side of the electrodes, another perforated plate was installed to simulate the geometric arrangement where each row of bags would have perforated plates on both sides, and no solid plates were used. The discharge electrodes were then centered between perforated plates located directly in front of the bags. With this arrangement, the perforated plates function both as the primary collection surface and as a protective grid for the bags. With the 200-acfm *Advanced Hybrid*™ filter, the perforated plate configuration produced results far better than in any previous *Advanced Hybrid*™ filter tests and provided adequate protection of the bags.

Based on the 200-acfm results, a perforated plate configuration was designed and installed on the 9000-acfm slipstream pilot unit at the Big Stone Power Plant. The differences between the new perforated plate design and the previous *Advanced Hybrid*™ filter can be seen by comparing Figure 1 with Figure 2. Figure 1 is a simplified top view of the 9000-acfm *Advanced Hybrid*™ filter configuration at the start of Phase III, which had a plate-to-plate spacing of 23.6 in. For the perforated plate configuration (Figure 2), the bag spacing was not changed, allowing use of the same tube sheet as in the previous configuration (Figure 1). However, the distance from the discharge electrodes to the perforated plates as well as the distance from the bags to the perforated plates can be reduced without compromising performance. Therefore, one of the obvious advantages of the perforated plate configuration is the potential to make the *Advanced Hybrid*™ filter significantly more compact than the earlier design.

Another difference is that directional electrodes are not required with the perforated plate design. With the previous design, directional electrodes (toward the plate) were needed to prevent possible sparking to the bags. This means that conventional electrodes can be used with the *Advanced Hybrid*™ filter. Electrode alignment is also less critical because an out-of-alignment electrode would simply result in potential sparking to the nearest grounded perforated plate, whereas with the old design, an out-of-alignment electrode could result in sparking to a bag and possible bag damage.

While the perforated plate configuration did not change the overall *Advanced Hybrid*™ filter concept (precollection of > 90% of the dust and enhanced bag cleaning), the purpose of the plates did change. The perforated plates serve two very important functions: as the primary collection surface and as a protective grid for the bags. With approximately 45% open area, there is adequate collection area on the plates to collect the precipitated dust while not restricting the flow of flue gas toward the bags during normal filtration. During pulse cleaning of the bags, most of the reentrained dust from the bags is forced back through the perforated plates into the ESP zone. The 9000-acfm results as well as the 200-acfm results showed better ESP collection than the previous design while maintaining good bag cleanability. The better

ESP collection efficiency is likely the result of forcing all of the flue gas through the perforated plate holes before reaching the bags. This ensures that all of the charged dust particles pass within a maximum of one-half of the hole diameter distance of a grounded surface. In the presence of the electric field, the particles then have a greater chance of being collected. In the old *Advanced Hybrid*™ filter design, once the gas reached the area between the electrodes and bags, it would be driven toward the bags rather than the plates, and a larger fraction of the dust was likely to bypass the ESP zone.

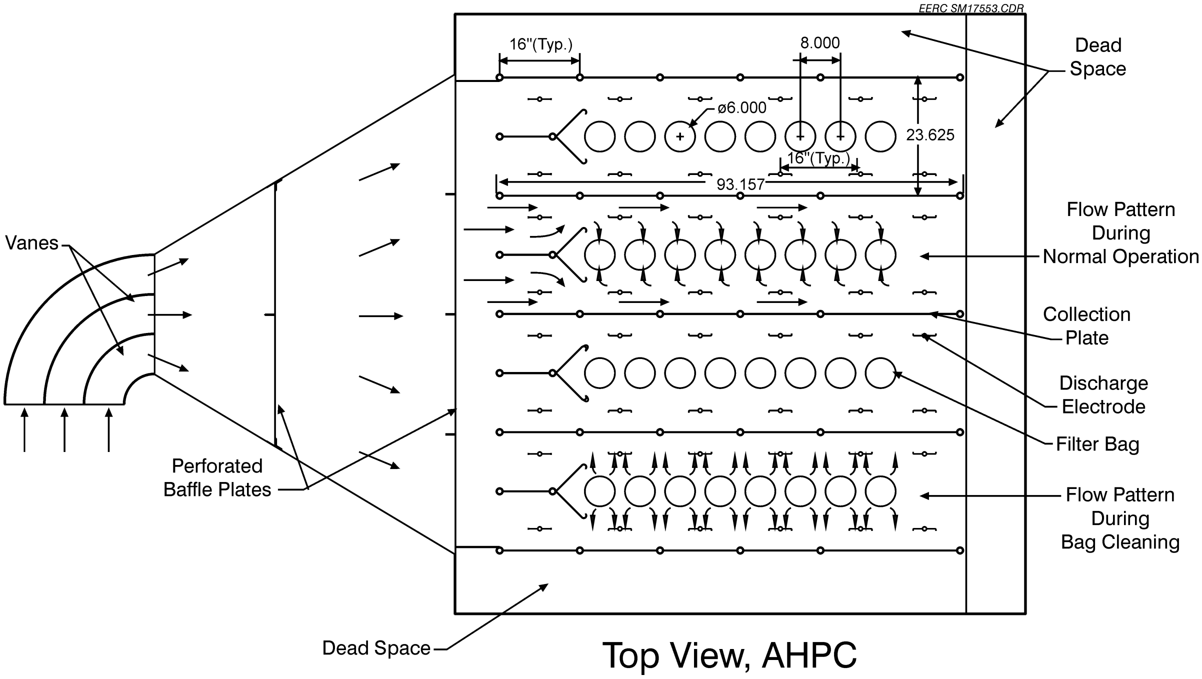


Figure 1. Top view of the old configuration for the 9000-acfm *Advanced Hybrid*™ filter at Big Stone.

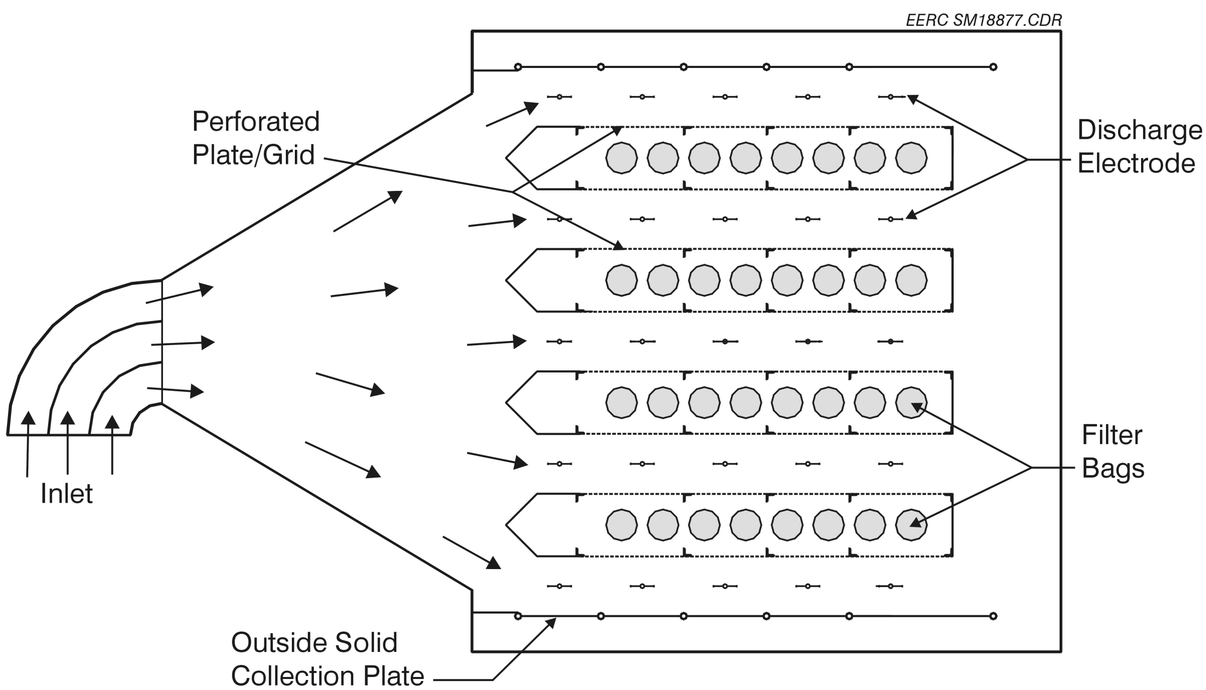


Figure 2. Top view of the perforated plate configuration for the 9000-acfm *Advanced Hybrid*™ filter.

1.3 Pressure Drop Theory and Performance Evaluation Criteria

Pressure drop across the bags is one of the main operational parameters that defines overall performance. It must be within capacity limits of the boiler fans at the maximum system flow rate. Since acceptable pressure drop is so critical to successful operation, a detailed discussion of the theory and factors that control pressure drop follows.

For viscous flow, pressure drop across a FF is dependent on three components:

$$dP = K_f V + K_2 W_R V + \frac{K_2 C_i V^2 t}{7000} \qquad \text{[Eq. 1]}$$

where:

dP = differential pressure across baghouse tube sheet (in. W.C.)
K_f = fabric resistance coefficient (in. W.C.-min/ft)
V = face velocity or A/C ratio (ft/min)
K_2 = specific dust cake resistance coefficient (in. W.C.-ft-min/lb)
WR = residual dust cake weight (lb/ft^2)
C_i = inlet dust loading (grains/acf)
t = filtration time between bag cleaning (min)

The first term in Eq. 1 accounts for the pressure drop across the fabric. For conventional fabrics, the pore size is quite large, and the corresponding fabric permeability is high, so the pressure drop across the fabric alone is negligible. To achieve better collection efficiency, the pore size can be significantly reduced, without making fabric resistance a significant contributor to pressure drop. The GORE-TEX® membrane filter media allows for this optimization by providing a microfine pore structure while maintaining sufficient fabric permeability to permit operation at high A/C ratios. A measure of the new fabric permeability is the Frazier number which is the volume of gas that will pass through a square foot of fabric sample at a pressure drop of 0.5 in. W.C. The Frazier number for new GORE-TEX® bags is in the range from 4 to 8 ft/min. Through the filter, viscous (laminar) flow conditions exist, so the pressure drop varies directly with flow velocity. Assuming a new fabric Frazier number of 6 ft/min, the pressure drop across the fabric alone would be 1.0 in. W.C. at an A/C ratio (filtration velocity) of 12 ft/min.

The second term in Eq. 1 accounts for the pressure drop contribution from the permanent residual dust cake that exists on the surface of the fabric. For operation at high A/C ratios, the bag cleaning must be sufficient to maintain a very light residual dust cake and ensure that the pressure drop contribution from this term is reasonable. The contribution to pressure drop from this term is one of the most important indicators of longer-term bag cleanability.

The third term in Eq. 1 accounts for the pressure drop contribution from the dust accumulated on the bags since the last bag cleaning. K_2 is determined primarily by the fly ash particle-size distribution and the porosity of the dust cake. Typical K_2 values for a full dust loading of pulverized coal (pc)-fired fly ash range from about 4 to 20 in. W.C.-ft-min/lb but may, in extreme cases, cover a wider range. Within this term, the bag-cleaning interval, t, is the key performance indicator. The goal is to operate with as long of a bag-cleaning interval as possible, since more frequent bag pulsing can lead to premature bag failure and require more energy consumption from compressed air usage. An earlier goal for the pilot-scale tests was to operate with a pulse interval of at least 10 min while operating at an A/C ratio of 12 ft/min. While this goal was exceeded in the pilot-scale tests, a pulse interval of only 10 min is now considered too short to demonstrate good *Advanced Hybrid*™ filter performance over a longer period. With a shorter pulse interval, the *Advanced Hybrid*™ filter does not appear to make the best use of the electric field, because of the reentrainment that occurs just after pulsing. Current thought is that a pulse interval of at least 60 min is needed to demonstrate the best long-term performance.

Total tube sheet pressure drop is another key indicator of overall performance of the *Advanced Hybrid*™ filter. Here, the goal was to operate with a tube sheet pressure drop of 8 in. W.C. at an A/C ratio of 12 ft/min. Note that the average pressure drop is not the same as the pulse-cleaning trigger point. For many of the previous and current tests, the pulse trigger point was set at 8 in. W.C., but the average pressure drop was significantly lower.

To help analyze filter performance, the terms in Eq. 1 can be normalized to the more general case by dividing by velocity. The dP/V term is commonly referred to as drag or total tube sheet drag, D_T:

$$\frac{dP}{V} = D_T = K_f + K_2 W_R + \frac{K_2 C_i V t}{7000} \qquad \text{[Eq. 2]}$$

The new fabric drag and the residual dust cake drag are typically combined into a single term called residual drag, D_R:

$$D_T = D_R + \frac{K_2 C_i V t}{7000} \qquad \text{[Eq. 3]}$$

The residual drag term then is the key indicator of how well the bags are cleaning over a range of A/C ratios, but may still be somewhat dependent on A/C ratio. For example, it may be more difficult to overcome a dP of 10 in. W.C. to clean the bags than cleaning at a dP of 5 in. W.C. For most baghouses, the residual drag typically climbs somewhat over time and must be monitored carefully to evaluate the longer-term performance. Current thought is that excellent *Advanced Hybrid*™ filter performance can be demonstrated with a residual drag value of 0.6 or lower.

Between bag cleanings, from the second term in Eq. 3, the drag increases linearly with K_2 (dust cake resistance coefficient), C_i (inlet dust concentration), V (filtration velocity), and t (filtration time). For conventional baghouses, the C_i term is easily determined from an inlet dust loading measurement, and approximate K_2 values can be determined from the literature or by direct measurement. However, for the *Advanced Hybrid*™ filter, the concentration of the dust that reaches the bags is generally not known and would be very difficult to measure experimentally. From the Phase I laboratory tests, results indicated approximately 90% of the dust was precollected and did not reach the fabric. However, this amount is likely to fluctuate significantly with changes to the electrical field and with the dust resistivity. Since C_i is not known, for evaluation of *Advanced Hybrid*™ filter performance, the K_2 and C_i can be considered together:

$$K_2C_i = \frac{(D_T - D_R)7000}{Vt} \qquad \text{[Eq. 4]}$$

Evaluation of K_2C_i can help in assessing how well the ESP portion of the *Advanced Hybrid*™ filter is functioning, especially by comparing with the K_2C_i during short test periods in which the ESP power was shut off. For the Big Stone ash, the K_2C_i value has typically been about 20 without the ESP field. For the 9000-acfm pilot *Advanced Hybrid*™ filter, longer-term K_2C_i values of 1.0 have been demonstrated with the ESP field on, which is equivalent to 95% precollection of the dust by the ESP. Again, the goal is to achieve as low of a K_2C_i value as possible; however, good *Advanced Hybrid*™ filter performance can be demonstrated with K_2C_i values up to 4, but this is interdependent on the residual drag and filtration velocity.

Eq. 4 can be solved for the bag-cleaning interval, t, as shown in Eq. 5. The bag-cleaning interval is inversely proportional to the face velocity, V, and the K_2C_i term and directly proportional to the change in drag before and after cleaning (delta drag). The delta drag term is dependent on the cleaning set point or maximum pressure drop as well as the residual drag. The face velocity, delta drag, and K_2C_i terms are relatively independent of each other and should all be considered when the bag-cleaning interval is evaluated. However, as mentioned above, the drag may be somewhat dependent on velocity if the dust does not clean off the bags as well at high velocity as at low velocity. Similarly, the K_2C_i is somewhat dependent on velocity for a constant plate collection area. At the greater flow rates, the SCA of the precipitator is reduced, which will result in a greater dust concentration, C_i, reaching the bags.

$$t = \frac{(D_T - D_R)7000}{VK_2C_i} \qquad \text{[Eq. 5]}$$

By evaluating these performance indicators, the range in possible A/C ratios can be calculated by using Eq. 1. For example, using the acceptable performance values of a 60-min pulse interval and a residual drag of 0.6, Eq. 1 predicts that a K_2C_i value of 2.33 would be needed when operating at an A/C ratio of 10 ft/min and a pulse trigger of 8 in. W.C. Obviously, deterioration in the performance of one indicator can be offset by improvement in another. Results to date show that performance is highly sensitive to the A/C ratio and that excellent *Advanced Hybrid*™ filter performance can be achieved as long as a critical A/C ratio is not exceeded. If the A/C ratio is pushed too high, system response is to more rapidly pulse the bags. However, too rapid of pulsing tends to make the residual drag increase faster and causes the K_2C_i to also increase, both of which lead to poorer performance. The design challenge is to operate the *Advanced Hybrid*™ filter at the appropriate A/C ratio for a given set of conditions.

1.4 9000-acfm Pilot-Scale Results

During the summer of 2002 the 9000-acfm *Advanced Hybrid*™ filter was operated from June 28 through early September with minimal changes to the operating parameters. This is the longest time the pilot unit was operated without interruption and is the best example of the excellent performance demonstrated with the 9000-acfm *Advanced Hybrid*™ filter. One of the main objectives of the summer 2002 tests was to assess the effect of carbon injection for mercury control on longer-term *Advanced Hybrid*™ filter performance. In order to achieve steady-state *Advanced Hybrid*™ filter operation prior to starting carbon injection, the *Advanced Hybrid*™ filter was started with new bags on June 28 and operated continuously until the start of the carbon injection for mercury control in August. Operational parameters are given in Table 1, and the bag-cleaning interval, pressure drop, and K_2C_i data from June 28 to September 3 are shown in Figures 3-5. The daily average pressure drop data increased slightly with time as would be expected after starting with new bags. When the carbon was started on August 7, there was no perceptible change in pressure drop. The bag-cleaning interval was somewhat variable as a result of temperature and load swings, but, again there was no increase when the carbon feed was started. The K_2C_i values are an indication of the amount of dust that reaches the bags and subsequently relate to how well the ESP portion of the *Advanced Hybrid*™ filter is working. Again, there was no perceptible change when the carbon was started. These data show that the *Advanced Hybrid*™ filter can be expected to provide good mercury removal with upstream injection of carbon without any adverse effect on performance.

From August 21 to August 26, the *Advanced Hybrid*™ filter current was deliberately reduced to 25 mA compared to the normal 55 mA setting (see Figures 3-5) to see if good mercury removal could be maintained. The bag-cleaning interval dropped to about one-half, and the K_2C_i value approximately doubled, which would be expected. Both of these indicate that about twice as much dust reached the bags at 25 mA compared to 55 mA. However, almost no effect on pressure drop was seen. This implies that it should be possible to optimize *Advanced Hybrid*™ filter operational parameters to get the best overall mercury removal while maintaining good *Advanced Hybrid*™ filter performance.

Table 1. 2.5-MW *Advanced Hybrid*™ Filter Test Parameters and Operational Summary, June 28 - September 2, 2002

A/C Ratio	10 ft/min
Pulse Pressure	70 psi
Pulse Duration	200 ms
Pulse Sequence	87654321 (multibank)
Pulse Trigger	8.0 in. W.C.
Pulse Interval	260 - 400 min
Temperature	260° - 320°F
Rapping Interval	15 - 20 min
Voltage	58 - 62 kV
Current	55 mA

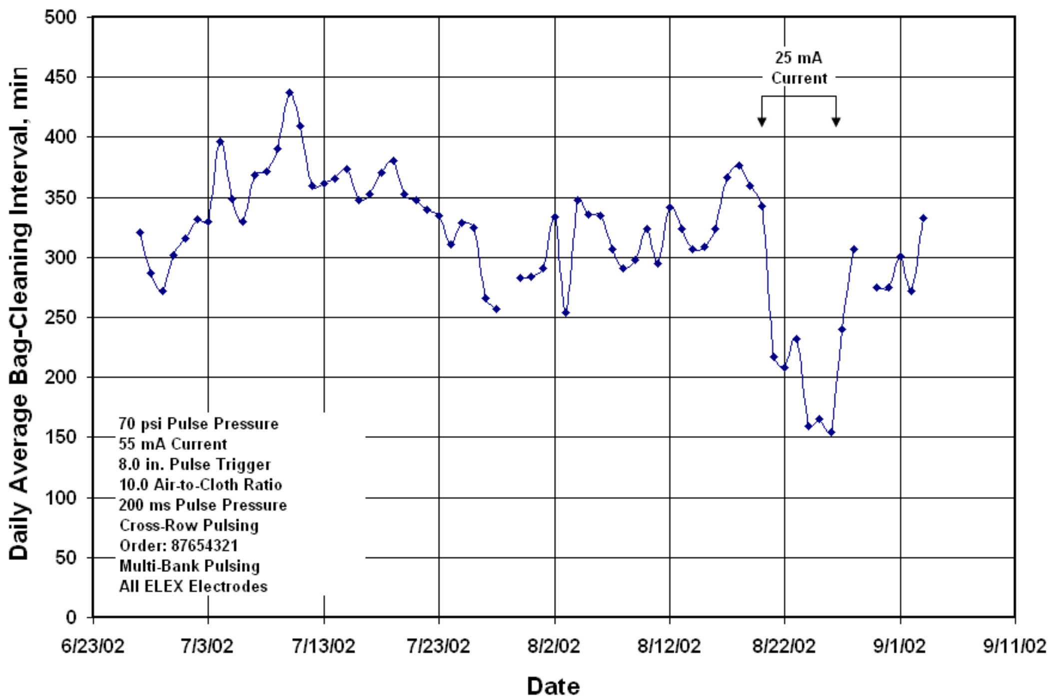


Figure 3. Daily average bag-cleaning interval for summer 2002 tests with the 9000-acfm *Advanced Hybrid*™ filter.

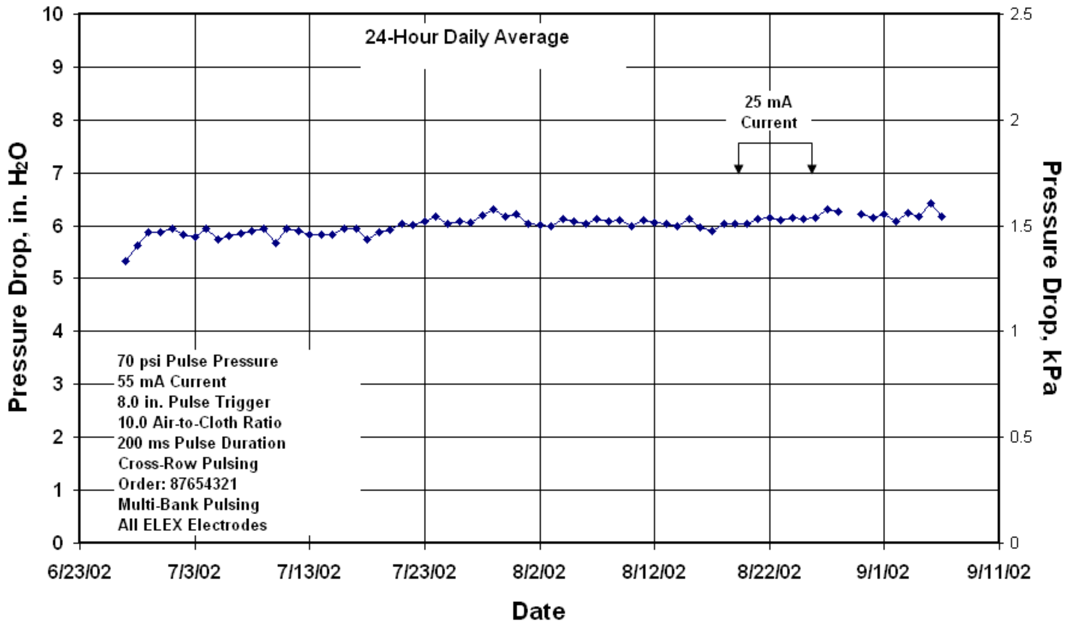


Figure 4. Daily average pressure drop for summer 2002 tests with the 9000-acfm *Advanced Hybrid*™ filter.

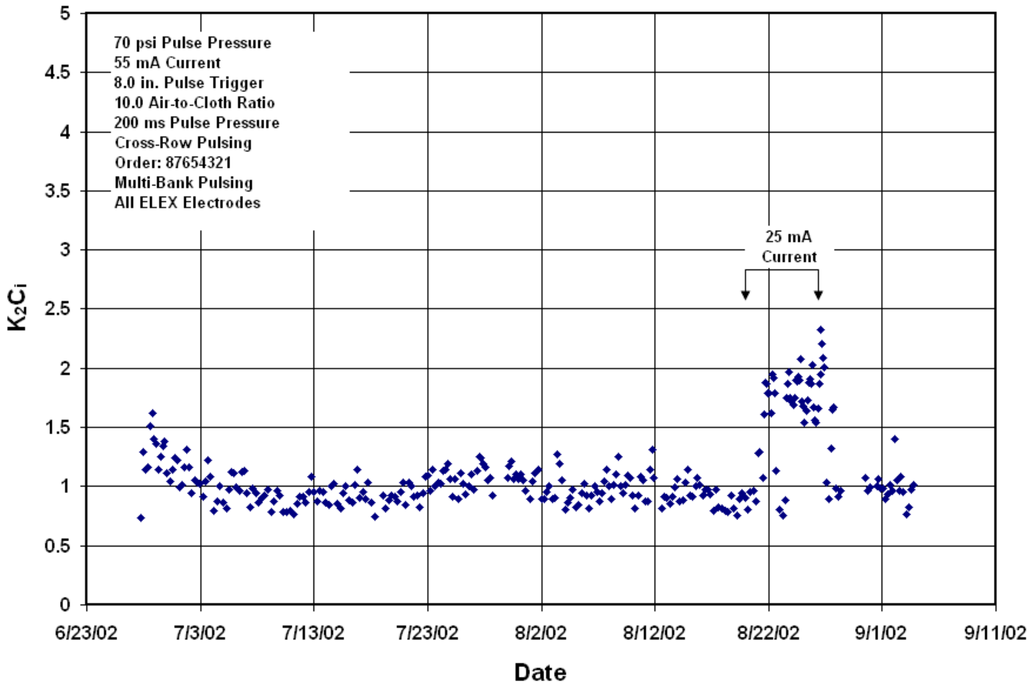


Figure 5. K_2C_i for summer 2002 tests with the 9000-acfm *Advanced Hybrid*™ filter.

A summary of the results in Table 2 shows the excellent operational performance achieved with the 9000-acfm at an A/C ratio of 10 ft/min.

Table 2. Summary of 9000-acfm Pilot-Scale Results from Summer 2002

A/C Ratio	10 ft/min
Average dP	~6 in. W.C.
Bag-Cleaning Interval	2–5 hr
Residual Drag	0.4–0.5
K_2C_i	0.9–1.5

The 9000-acfm pilot *Advanced Hybrid*™ filter was also used to vary the operational parameters to assess the most critical effects. One of the most important findings was the observed significant effect of the pulse interval on the K_2C_i value, as shown in Figure 6. The large increase in K_2C_i at the lowest pulse intervals indicates that the benefit of the electric field is diminished at lower pulse intervals. This indicates that for good *Advanced Hybrid*™ filter performance, a minimum allowable pulse interval should be established. Based on Figure 6, a 60 min pulse interval would be a good minimum performance goal.

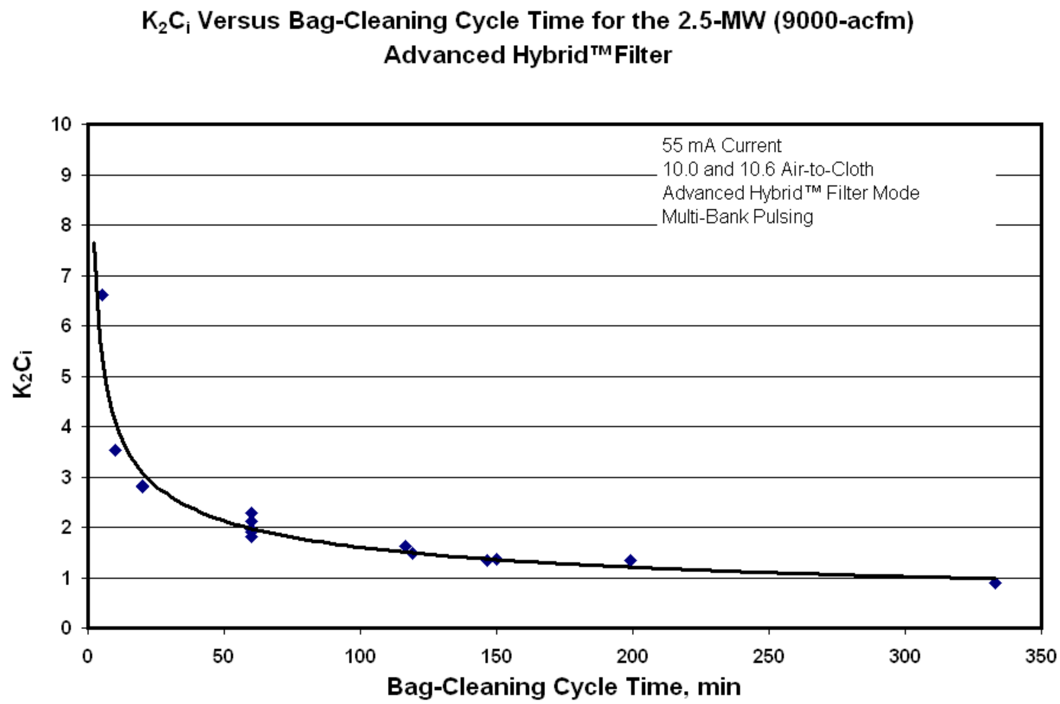


Figure 6. Effect of pulse interval on K_2C_i for 9000-acfm pilot *Advanced Hybrid*™ filter.

1.5 Full-Scale Design and Differences Between Full and Pilot Scale

The original ESP at Big Stone consisted of a Lurgi-Wheelabrator design with four main chambers and four collecting fields in series within each chamber. Only the last three fields in each chamber were converted into an *Advanced Hybrid*™ filter while the first field was unchanged (Figure 7). Since the ESP plates are 40 ft high, but the *Advanced Hybrid*™ filter bags are only 23 ft long, there is a large open space between the bottom of the bags and the hoppers (Figure 8). The outer six compartments (Figure 7) are arranged with 20 rows and 21 bags per row, while the six inner compartments have 19 rows with 21 bags per row. The total number of planned bags for the 12 compartments was 4914. However, because of a spacing limitation from the electrode rapping mechanism, a total of 81 bags had to be removed, so the total number of bags in service is 4834.

The main differences between the 2.5-MW pilot *Advanced Hybrid*™ filter and the full-scale Big Stone *Advanced Hybrid*™ filter are as follows:

- The pilot unit has a small precollection zone consisting of one discharge electrode, while the full-scale unit has no precollection zone (without the first field on). The effect would be better ESP collection (lower K_2C_i) in the pilot unit. The pilot unit has shorter bags, 15 ft versus 23 ft for the full-scale *Advanced Hybrid*™ filter. The expected result would be better bag cleaning with the pilot unit (lower residual drag).

- The full-scale *Advanced Hybrid*™ filter has an ESP plate spacing of 12 in. compared to 13.5 in. for the pilot-scale unit. The expected result is somewhat better ESP collection efficiency.

- The entrance velocity of the flue gas is 4–8 ft/s for the full-scale unit versus 2 ft/s in the pilot-scale unit. The expected effect is better ESP collection efficiency with the pilot unit.

- The pilot unit has very uniform side inlet flow distribution while the full-scale *Advanced Hybrid*™ filter has flow from the side for the first *Advanced Hybrid*™ filter compartment and from the bottom in the back 2 compartments.

In the pilot unit all of the flow is uniformly distributed from the side and none of the flow comes from the bottom. In the full-scale *Advanced Hybrid*™ filter, flow entering the first *Advanced Hybrid*™ filter chamber comes from the side (similar to the pilot unit). The flow to the back two compartments must first travel below the first *Advanced Hybrid*™ filter compartment and then either directly up from the bottom into the compartment or up from the bottom into the areas between compartments and then horizontally into the compartments (Figure 9).

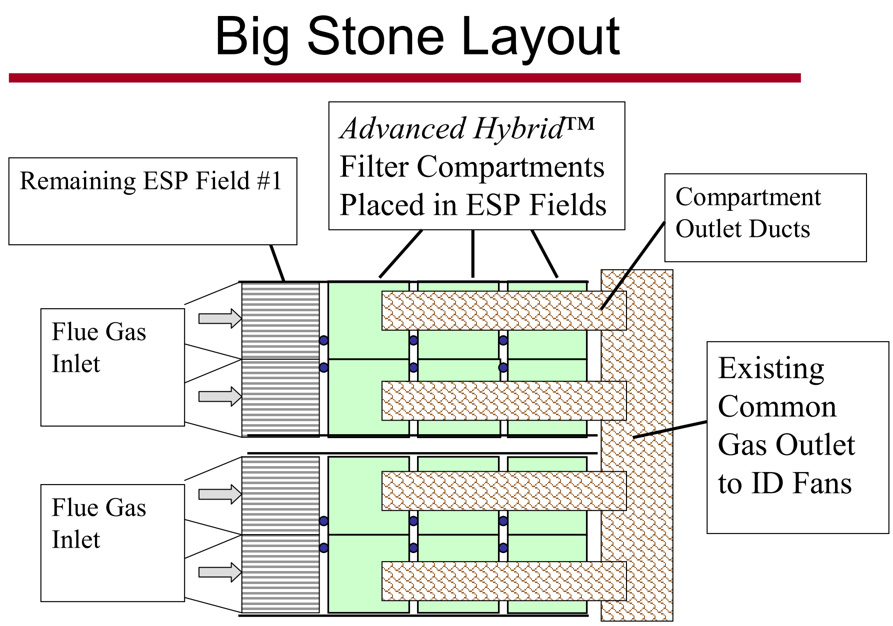


Figure 7. Top view of the *Advanced Hybrid*™ filter full-scale retrofit configuration at Big Stone.

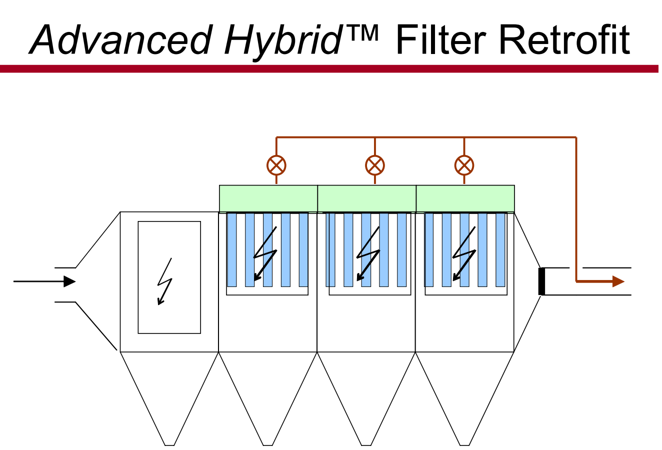


Figure 8. Side view of the *Advanced Hybrid*™ filter full-scale retrofit configuration at Big Stone.

2.0 EXPERIMENTAL

2.1 Independent Characteristics

2.1.1 Independent Characteristic Chart

The following chart lists the specific independent characteristics of the Advanced Hybrid System. If changes are made to the independent data, they will be described in the section listed under the "Notes" column.

Table 3.

Data	Status	Notes
ESP Collecting Surface	170,500 ft^2	Unchanged
# of Discharge Electrodes	2,706	Unchanged
# of Filter Bags	4834	Unchanged
Filter Bag Dimensions	7 Meters Long, 6 Inches Diameter	Unchanged
Filter Bag Surface Area	36.07 ft^2	Unchanged
Filter Bag Material	4834 GORE No-Stat filter Bags	Unchanged
Pulse Pressure	80 psi	Unchanged
Cleaning Mode	dP control	Unchanged
TR Rating of AH Field	1500 ma, 55 kV	Unchanged
TR Rating of Inlet ESP Field	2000 ma, 55 kV	Unchanged
Inlet ESP Field Data		
Inlet Field Dimensions[1]	45 gas passages, 40 feet high, 14 feet deep/chamber	Unchanged
Inlet Field Plate Area[1]	50,400 ft^2	Unchanged
Inlet Field Electrodes[1]	Wheelabrator bed frame "Star" Electrodes	Unchanged

[1]The inlet ESP filed was left in place. The design is the original configuration as installed in 1975. It is not the intention to operate the inlet field, however it was left in place as an added benefit of the system.

2.1.2 Bag Layout

The following is a description of the number and type of bags in the system. Some plugging of bags may occur, but in general, this should be an accurate description of the system with regards to filtration distribution. A diagram of the bag layout is included in Appendix B23.

Table 4. Bag Layout and Type Description

Compartment	Number of Bags	Bag Type
Chamber 1A Field 2	**413**	**GORE-TEX™ Felt/GORE-TEX™ Membrane**
Chamber 1A Field 3	**413**	**GORE-TEX™ Felt/GORE-TEX™ Membrane**
Chamber 1A Field 4	**413**	**GORE-TEX™ Felt/GORE-TEX™ Membrane**
Chamber 1B Field 2	**392**	**GORE-TEX™ Felt/GORE-TEX™ Membrane**
Chamber 1B Field 3	**392**	**GORE-TEX™ Felt/GORE-TEX™ Membrane**
Chamber 1B Field 4	**393**	**GORE-TEX™ Felt/GORE-TEX™ Membrane**
Chamber 2A Field 2	**393**	**GORE-TEX™ Felt/GORE-TEX™ Membrane**
Chamber 2A Field 3	**393**	**GORE-TEX™ Felt/GORE-TEX™ Membrane**
Chamber 2A Field 4	**393**	**GORE-TEX™ Felt/GORE-TEX™ Membrane**
Chamber 2B Field 2	**413**	**GORE-TEX™ Felt/GORE-TEX™ Membrane**
Chamber 2B Field 3	**413**	**GORE-TEX™ Felt/GORE-TEX™ Membrane**
Chamber 2B Field 4	**413**	**GORE-TEX™ Felt/GORE-TEX™ Membrane**

2.2 Dependent Characteristics

2.2.1 Dependent Data

The dependent data is largely presented in graphical format in the Appendix. The specific data points that are instrumented and presented are as follows;

Plant Gross Load: Continuously monitored TDC-3000 calculated value based on the generator output voltage and current. When the plant trips offline or shuts down for maintenance, the plant gross load will be zero.

Total Flue Gas Flow: Continuously monitored using United Science Inc.'s Ultra Flow 100 ultrasonic flow monitor. The flow monitor is located at the stack midlevel (see position #6 on the figure in 2.2.2). The readout of the flow monitor is in kscfm using 68^{o}F and 29.92 in HG as standard conditions. The flow is converted to kacfm using the following equation:

$$\text{Gas Flow (kacfm)} = \frac{\text{(Gas Flow(kscfm)*(460 + Inlet Gas Temp}^{o}\text{ F)}}{(460+68^{o}\text{ F)}} * \frac{29.92\text{ in HG}}{\text{(28.56 in HG + AHPC outlet Pressure)}}$$

Inlet Flue Gas Temperature: Continuously monitored using a grid of Type E thermocouples. The thermocouples are located at the AHPC inlet (see position #1 on the figure in 2.2.2). There are eight thermocouples at the inlet of each of the four AHPC chambers for a total of 32 thermocouples.

Tubesheet Differential Pressure: Continuously monitored on two of the twelve compartments. Pressure taps above and below the tubesheet (see positions #3 and #4 on the figure in 2.2.2) are equipped with Honeywell 3000 Smart DP Transmitters.

Flange–Flange Differential Pressure: Continuously monitored using two Honeywell 3000 Smart DP Transmitters at the AHPC inlet (see position # 2 in the figure in 2.2.2) and two Honeywell 3000 Smart DP Transmitters at the AHPC outlet (see position #5 on Diagram 1). Continuously calculated by the TDC- 3000 by taking the difference between the flue gas pressure at the AHPC inlet and outlet.

Air-to-Cloth Ratio: Calculated by dividing the Gas Flow (acfm) by the total surface area of the bags.

Opacity: Continuously measured by the plant opacity monitor, Monitor Labs Model #LS541. Opacity is measured in the Plant Stack, position 6 on the figure in 2.2.2. Position 6 is approximately at the 300 ft. level from grade.

Flue Gas Outlet Pressure: Continuously monitored using two Honeywell 3000 Smart DP Transmitters at the AHPC outlet (see position #5 in the figure in 2.2.2). The inlet pressure can be determined by the difference between the outlet pressure, and the flange-to-flange pressure drop.

Temperature per Chamber: See Inlet Temperature above.

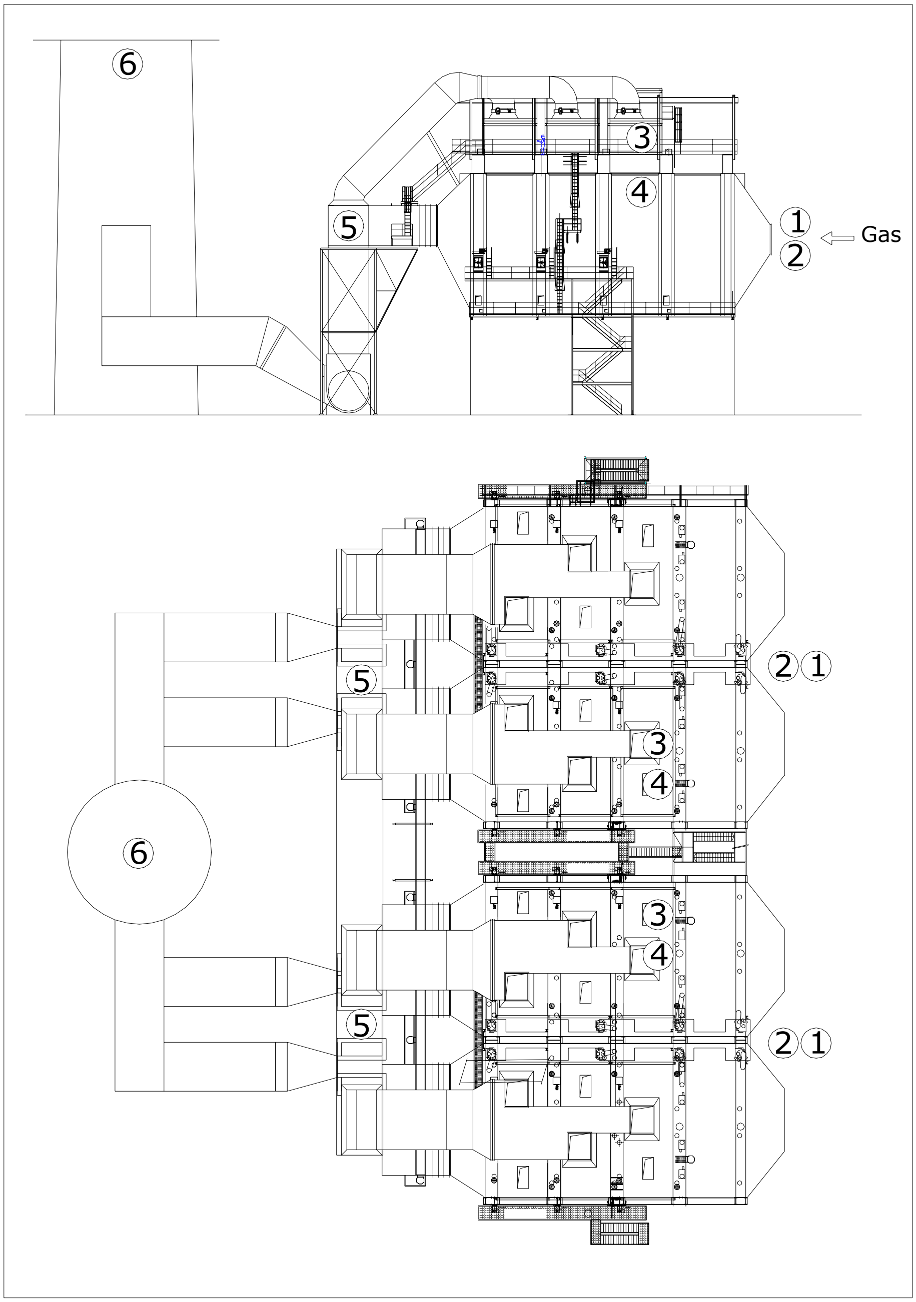
ESP Power Consumption: Continuously monitored with a watt-hour meter to each chamber.

Compressed Air Flow: Continuously monitored using a Diamond II Annubar flow sensor equipped with a Honeywell 3000 Smart DP Transmitter. This ANNUBAR instrument is in the compressed air supply line after the compressors but before the desiccant dryer.

The non-instrumented data that can be found in the appendix is as follows

- Coal Analysis
- Flyash Analysis
- Coal and Alternative fuel Burned

2.2.2 Instrument Location Diagram



1 & 2: Advanced Hybrid Inlet
3 & 4: Above and Below Tubesheet
5: Advanced Hybrid Outlet
6: Plant Stack

2.2.3 Data Retrieval

Big Stone Plant's Honeywell TDC-3000 process control system monitors and controls a large number of actuators, sensors, and processes using PID controllers, programmable logic controllers, and special-purpose programs. Data gathered by the TDC-3000 is retrieved using an existing plant historian database. The dependent characteristic data presented in this report is calculated using 60-minute averages of the TDC-3000 readings, which are recorded every minute.

2.2.4 Data Reduction

Reported NO_X and SO_2 emissions have had 5% of data removed due to erroneous spikes occurring during daily calibration of CEMS instrumentation. No other assumptions or restrictions were used to transform the raw measured data into a form usable for interpretation.

3.0 RESULTS AND DISCUSSION

3.1 General Results and Discussion

3.1.1 Chronological History of Significant Accomplishments

Quarter 1 (October 2002 – December 2002)

System Startup	October 2002
Rapper Problems Realized	November 2002
Pulse Valve Problems Realized	November 2002
EERC Testing (99.99% particulate capture goal met)	November 2002
Inlet Field Energized	December 2002

3.1.2 Discussion of Results of Significant Accomplishments

Initial Startup Problems

The Big Stone Plant was put on-line on October 25 at 17:37, which is the official beginning of commercial operation of the Advanced Hybrid system. Startup and checkout of the system went fairly smoothly. There were few significant issues that came up during system startup, as described below.

First, there appeared to be a problem with damper operability as the dampers were commanded to open and close to check functionability. The indication for opened and closed did not come in to the plant control room. This was a simple limit switch setting in the controller. Specific training needed to take place between the ELEX startup engineers and Big Stone Plant personnel, as setting the limit switches required knowledge of procedures that, if not followed correctly, would result in the unintended dismantling of the controller body. The manual wheel on the actuator would unscrew from the controller body allowing the oil to leak out, thus rendering the actuator inoperable. This occurred 3 or 4 times before startup personnel familiarized themselves and from that point it proceeded well.

Second, ice had formed in the pressure sensing lines after the Advanced Hybrid system (just prior to the ID fans). At startup, the pulse controller used the flange-to-flange pressure drop as the input for pulse frequency. If a high enough differential had been realized, the system would not have started pulsing because there would have been no pressure measurement. This could have delayed startup. The sensing lines were about 70 feet long and run 50 feet overhead. However, the ice buildup was not significant and was cleared using torches and poke rods.

Third, pre-coating the bags was a new experience and the procedure was not well developed. The bag manufacturer deemed pre-coating the bags necessary. A supplier delivered crushed limestone via truck and had to wait until the system was ready to be pre-coated. Pre-coating was a manual operation, as Big Stone Plant operators moved a four inch flexible line from duct to duct to inject the crushed limestone into the appropriate chambers. This process directly added to the critical path of the outage, and therefore the time that it takes to pre-coat the bags is directly related to delays in starting up the unit. If this must continue in the future, it would be necessary to install a silo and automatic feed system so the process could be completed in minutes rather than hours. This was an oversight in the project design and plans should be taken into account for future installations if bag pre-coating is necessary.

Fourth, the pulse system was not tested with compressed air until the system was started up. The system worked to pulse the bags, however it required the ELEX startup engineers several days to work the bugs out of the pulsing program to consider it functional for normal operation.

Overall system startup went well and fairly trouble free. The operational issues listed above are only the points of interest, and in general, the system components fit and worked together.

Operational Experience

The operational experience was mixed during the initial phases of operation. W.L. Gore and Associates produced the graph in Figure 1. The graph shows that the drag on the system was running between 0.9 and 1.0 INH2O/ft/min during the first few days of startup. However, the whole story includes the bag pulse

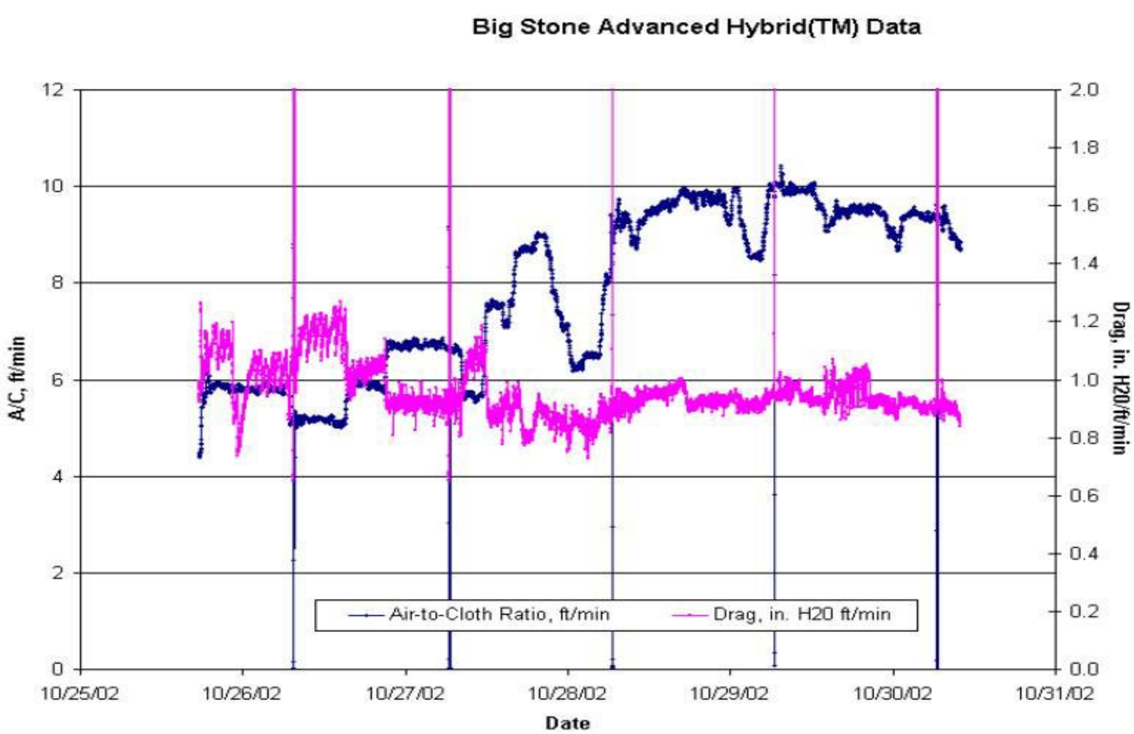


Figure 9 - A/C Ratio and drag during the first week of operation

frequency. The system is attempting to run at a flange-to-flange pressure drop at 9.0 INH2O. It is accomplishing this by changing the rate at which the 504 pulse valves are firing. That rate is not currently being recorded so there is no history. In Figure 1, we do not know if the pulse valves are running continuously (about 1.2 seconds between pulses), or one tenth of that (about 12 seconds between pulses), or any amount between. As a result, it is very difficult to put a meaningful analysis together on how the system was operating. The system was pulsing very quickly (about 1.2 – 2.4 seconds between pulses), within days of initial operation. During the first month of operation, it was deemed necessary to get some type of pulse signal into history. Eventually (around December 5, 2002) a system was installed to measure and record the pulse frequency. By that time the system was in constant pulsing while at full load, and the recorded history was not very useful.

One of the first mechanical issues seen after startup was sticking solenoid valves. On October 28, the Monday after startup, it was noticed that a fair number of solenoid valves were not operational. This was traced to the compressed air supply lines that were not blown clear prior to being connected. The cutting oil and debris in the lines contaminated the solenoid valves. The Big Stone Plant technicians disassembled and cleaned a portion of the solenoid valves to alleviate this problem. After the initial rash of sticking valves, the problem disappeared.

One of the first tests run was the off -line bag cleaning function of the Hesch pulse valve controller. This function intended to enable one compartment (1/12 of the total) to be isolated from gas flow, and pulsed without gas going through the bags. This should have resulted in improved cleaning and a lower differential pressure. This feature was tested on October 29, but did not work as the pulse valves did not activate when the damper was closed to the compartment. This was a software problem and a software update was shipped from Hesch and installed on November 12. The software fix did allow the functionality of off-line cleaning, but through intermittent tests, it was not clearly defined as a benefit to the normal cleaning modes and was not implemented as the normal mode. The differential was too high with 12 compartments in service, and taking one of the compartments out of service raised the overall differential pressure to intolerable levels.

On October 31, forced cleaning mode was also tested. This mode continuously pulsed the cleaning valves. This also did not work correctly, but the software fix mentioned in the paragraph above resolved this issue.

During the first week of operation, two filter bags were found in the ash hoppers below the Advanced Hybrid system. This was a strong concern at the time, as we were not sure if all of the bags were prone to being dislodged from the cage and tubesheet fit. It appears there were only a few ill-fitting or mis-installed bags which came loose and fell. Two bags represents 0.04% of the total bags installed.

The Big Stone Plant was derated on November 9 to replace these two bags, and inspect that portion of the AHPC. One bag was removed for examination by W.L. Gore personnel. During startup and limited first data, from the first two weeks, the bags were in good shape and there were no adverse effects from startup or short-term operation.

Alternative fuels burned at Big Stone were started back up on November 1. The specific amounts can be seen in Appendix B14.

On November 18, the Energy and Environmental Research Center (EERC) performed the first stack test to evaluate the particulate capture of the system. The full report can be found in Appendix B24, but the summary chart in Figure 2 shows that the particulate capture of the system was very high as expected.

Date	Sample Method	Advanced Hybrid™ Inlet Dust Loading, grains/scf	Advanced Hybrid™ Inlet[1] Dust Loading, $lb/10^6$ Btu	Stack Dust Loading, grains/scf	Stack[1] Dust Loading, $lb/10^6$ Btu	Particulate Collection Efficiency, %
11/18/2002	EPA Method 17			0.00002	0.00003	99.998
11/19/2002	EPA Method 29	1.02092	1.38378			
	Multicyclones	0.64099	0.86882			
11/20/2002	EPA Method 17			0.00006	0.00008	99.994
	EPA Method 29	0.85856	1.16372			
	EPA Method 29	0.92151	1.24904			
11/21/2002	EPA Method 17			0.00003	0.00004	99.997
	Multicyclones	0.66113	0.89611			
	Multicyclones	0.70044	0.94940			

[1] Values were calculated based on the Fd factors shown in Table 3 for 100% PRB.

Figure 10 - Results of Stack Testing by the EERC

During the month of November, two more bags were found in the hoppers. On November 23, three fourths of the system was removed from service to complete an inspection of the system. Two more bags that had fallen from the tubesheet were located and replaced. There was significant ash buildup on the perforated plates and the rapping schedule was adjusted for a higher frequency of rapping.

The Big Stone Plant electricians completed routine external inspections of the plate rapper system by manual operation of the rapper system and observation from the exterior. During one of these inspections in later November, it was found that one of the rappers in Chamber 2B was not turning. Electricians disconnected the motor and verified that rapper shaft was jammed internal to the system. On the 17th of December, the system was removed from service and inspected. At the time, the rapper shaft was found to need repairs; there was a broken hammer, bent rollers, and hammer to anvil alignment problems. The collar that grips the rapper shaft appeared loose. There were two fundamental issues with the reliability of the plate rappers. First, the rapper shafts were the wrong diameter. The collars that grip these shafts to keep them from floating laterally could not effectively maintain the shaft alignment. Second, the internal walkways were mounted fixed at the opposite wall as the fixed point of the rapper shafts. As the system heats up when flue gas is put through it, the walkways and the rapper shafts expand in opposite directions and misalignment between the rapper hammers and the anvils occurs. The system was also taken down on December 31, with misalignment of the rapper shaft to the walkway components the cause of another jammed rapper.

The Goyen pulse valves appeared to have an operational problem during the month of November as observed by listening to the valves operating. Occasionally a valve would not pulse with as much energy as the adjacent valve. This indication was a loud squeak or a muffled noise as opposed to a strong pulse. A Goyen representative was dispatched to the site on December 18 to review the operation of the valves. He recommended removal of the silencers on each valve to reduce the noise. It is possible that these silencers might have been plugged during startup or normal operation. All 504 silencers were removed from the pulse valves and it seemed to take care of the problem. No significant improvement in overall differential pressure was realized, so it is doubtful if more than 5 – 10% of the valves had problems with these silencers.

As the differential pressure had risen in the first couple of months of operation, it was decided to energize the unmodified inlet ESP fields to reduce the ash loading to the Advanced Hybrid system. This was planned as an only-in-an-emergency contingency, but was implemented so a performance and improvement plan could be evaluated. There is one inlet field of original Wheelabrator ESP in each chamber. These fields were energized on December 12 and have remained in service.

There appears to be a discrepancy in the gas flow and sizing of the system. The system was sized on a stoichiometric flow value based on fuel flow into the boiler, the measured oxygen level after the economizer and the air heater leakage as has been measured at the plant. The flow value was 1,824,000 acfm. However, the stack flow monitor is reading 5 – 15% more flow than is predicted by the stoichiometric balance. Using the 1,824,000 acfm value and dividing by the installed cloth surface area would result in an air-to-cloth ratio of 10.5 fpm. The goal of the technology was demonstration of acceptable performance at an air-to-cloth ratio of 12 fpm so that it would be the clear economic choice when compared to other retrofit technologies. The gas flow through the system presented in Appendices B2, B3, & B7 are based on the stack flow monitor, which reads 5 – 15% more than the stoichiometric balance predicts.

4.0 CONCLUSIONS

Operation

The Advanced Hybrid system was put into commercial operation on October 25, 2002 at 17:37. Startup of the system went well, and a few minor issues were overcome to get the system into operation. There appear to be two primary equipment issues that remain a concern for continued operation;

- Plate rapper alignment concerns
- Compressed air flow limitations

The plate rappers will need a solution to the existing problem described in section 3.1.2. The solution is not yet identified, however, it appears that the problem is only affecting one or two of the plate rappers systems and the ability to operate those systems. The concern is one more of long-term wear and reliability of components rather than a day-to-day performance concern. Any resolution is unlikely to impact overall system performance.

If the compressed air demands for cleaning the bags remains at 2,000 acfm, a solution for the restrictions caused by the existing regulators must be found. At the current rate of compressed air usage, the pulse headers are not filling up to capacity for a full-pressure pulse. If this restriction is removed, it could affect performance, but again would likely be a slight improvement.

Performance

There is significant graphical performance data included in the Appendix of this report. The fundamental performance parameters can be broken down into the following four pieces that really describe the heart of the performance evaluation of the Advanced Hybrid system. These parameters are;

- opacity (Appendix B8)
- air-to-cloth ratio (Appendix B7)
- tubesheet dP (Appendix B5)
- compressed air flow (Appendix B22)

The opacity since the unit has started up has been very low (less than 2%). Typical opacity before the Advanced Hybrid system was installed averaged 12 – 18 %. However, the plant opacity monitor is limited in the capability to report opacity with a high degree of accuracy. The alignment of the instrument is made through an optical lens which is difficult to perform and relies on human interpretation. Two separate individuals could align the system and the reading could result in +/- 5% opacity. The low opacity readings are verified through the stack testing that was performed by the EERC. These tests demonstrated that greater than 99.99% of the particulate was captured.

The air-to-cloth ratio is the duty cycle of the Advanced Hybrid system. Since startup, using the plant stack flow monitor (which could be reading 5 – 15% high, see section 3.1.2), the system has been running at 10 – 11 fpm. Whether this air-to-cloth ratio is aggressive or not seems to be a point of debate between the team members. It is certain that as the ambient conditions rise at the plant, the temperature into the Advanced Hybrid system will increase. This will decrease the density of flue gas, increase the volumetric flow of flue gas, and raise the air-to-cloth ratio of the system. Using the stack flow monitor, it is likely that we will see an air-to-cloth ratio of 12 fpm this summer.

The tubesheet dP has varied from 6.5 INH2O at startup, to 9.5 INH2O in mid December, to 8.5 INH2O at the end of the year. The initial rise in differential pressure seems to be consistent with previous experience of the bags "seasoning" as they begin normal operation. However, 9.5 INH2O is a very high level of differential pressure and this will likely cause the unit to restrict load as temperatures and the resultant air-to-cloth ratio increase during the summer period. The dropping of the differential pressure from 9.5 to 8.5 is likely the result of operating the inlet ESP field and slightly increasing the pulse pressure at the headers. This parameter is key to the ability of the power plant to carry full load.

Although it was not anticipated to be a key performance parameter, the compressed air flow reading has turned out to be a good tool when analyzing long-term performance data. Through operational experience, realistic operation indicates that continuous or constant pulsing can be supported with a compressed air flow of approximately 2200 acfm. As system performance improves, pulsing decreases and compressed air flow decreases. As we look at the graph in Appendix B22, it is clear that at full load operation, the system has been at nearly continuous pulsing from approximately November 11th.

<u>Summary</u>

Overall, system operation has been satisfactory, but there are significant issues with regards to performance. An evaluation of performance will be done in the next quarter to establish baseline performance and compare this to the project and technology goals. Various equipment issues will need to be resolved as well. Finally, more operating experience is needed to evaluate the viability of the technology.

5.0 APPENDICES

APPENDIX A - COMMENTS ON ANOMALIES OF GRAPHICAL DATA

Appendix B5 & B6. The initial dP data was not historized correctly, so the first couple of days of dP history do not exist in the Plant Historian.

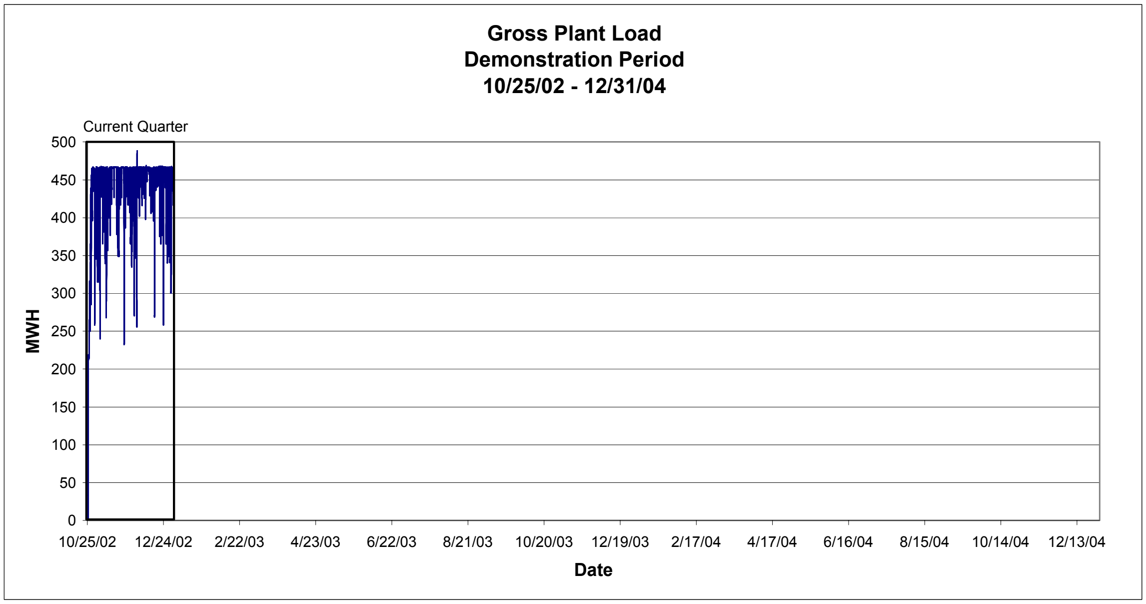
Appendix B19. Significant increases in Chamber Power typically indicate periods where the initial inlet field was energized, although spikes also occur during periods of reduced loading on the unit.

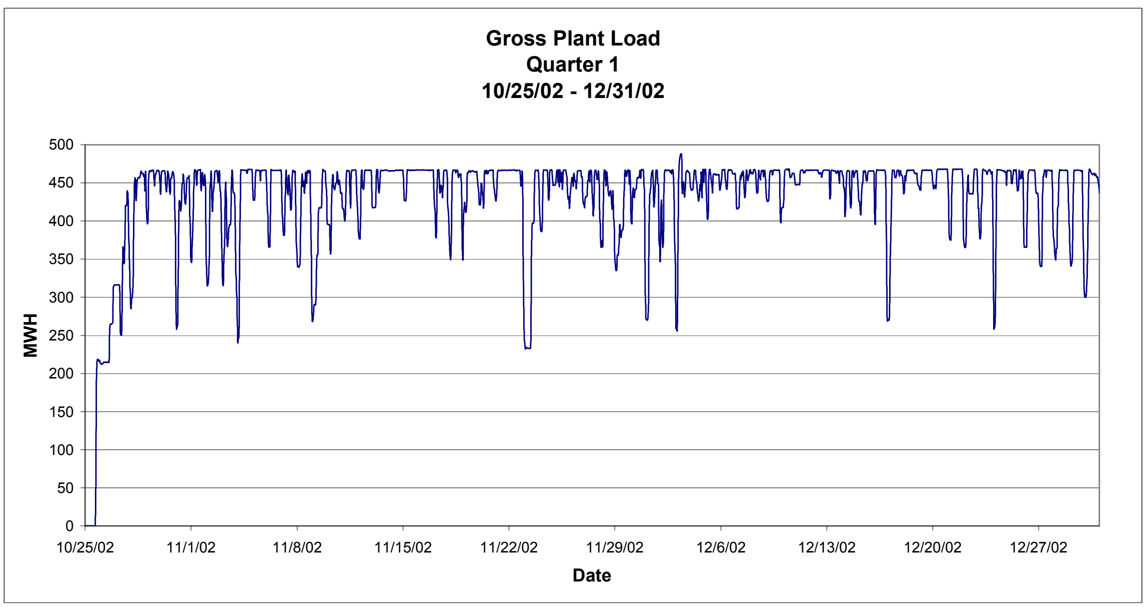
Appendix B15. bam, ebm, etc. are Powder River Basin mine codes

Appendix B14 & 15. The “adjustment” refers to an end of the month correction based on a comparison between visual levels and bookkeeping levels.

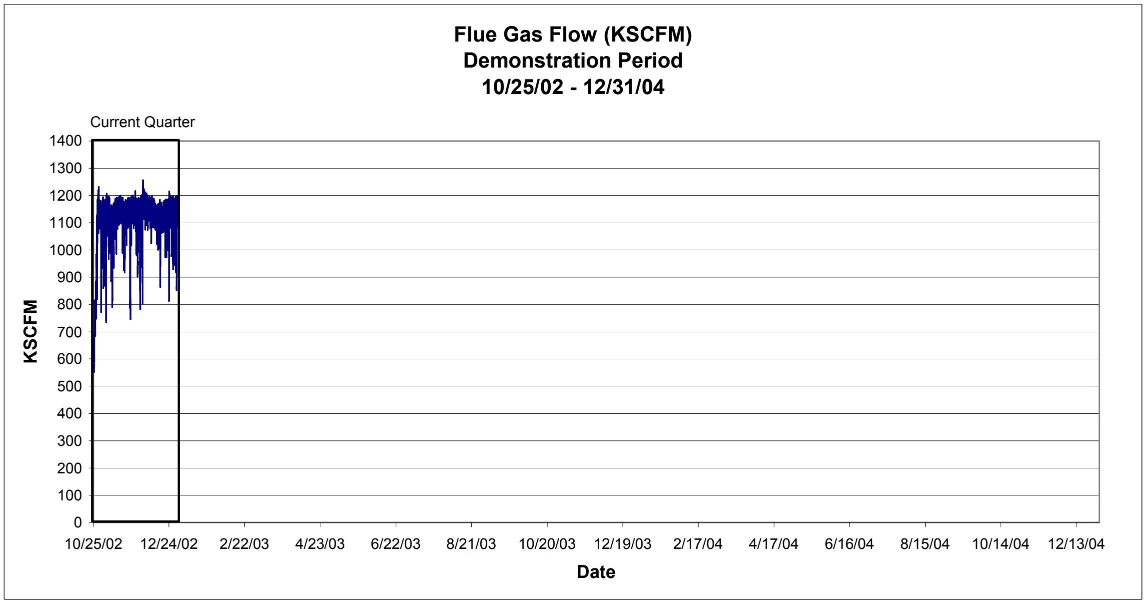
APPENDIX B – GRAPHICAL & TABULAR PERFORMANCE DATA

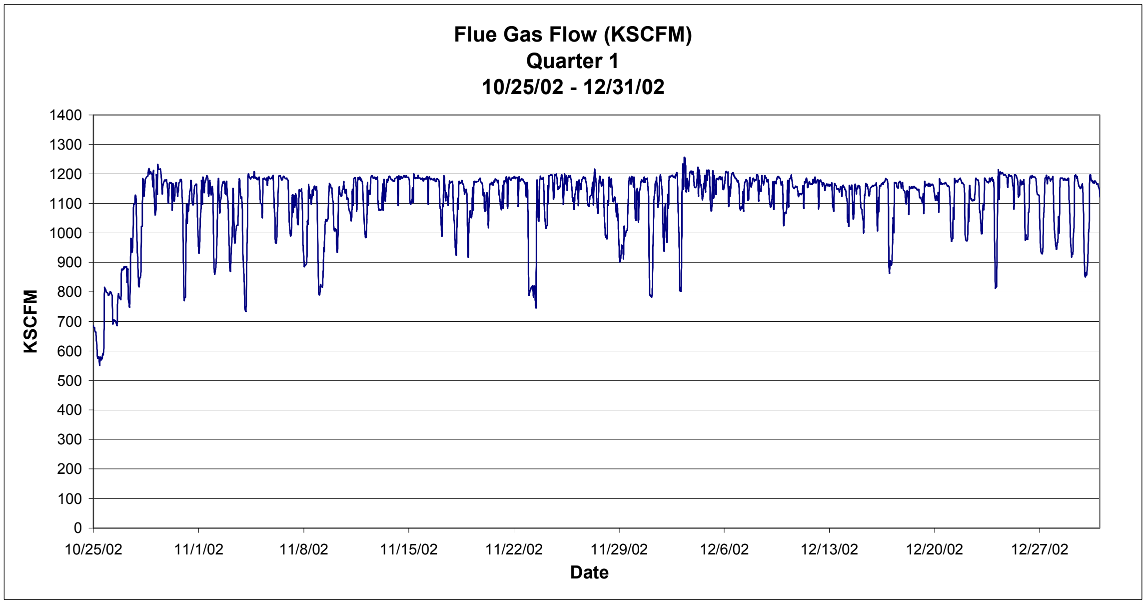
B1 Gross Plant Load



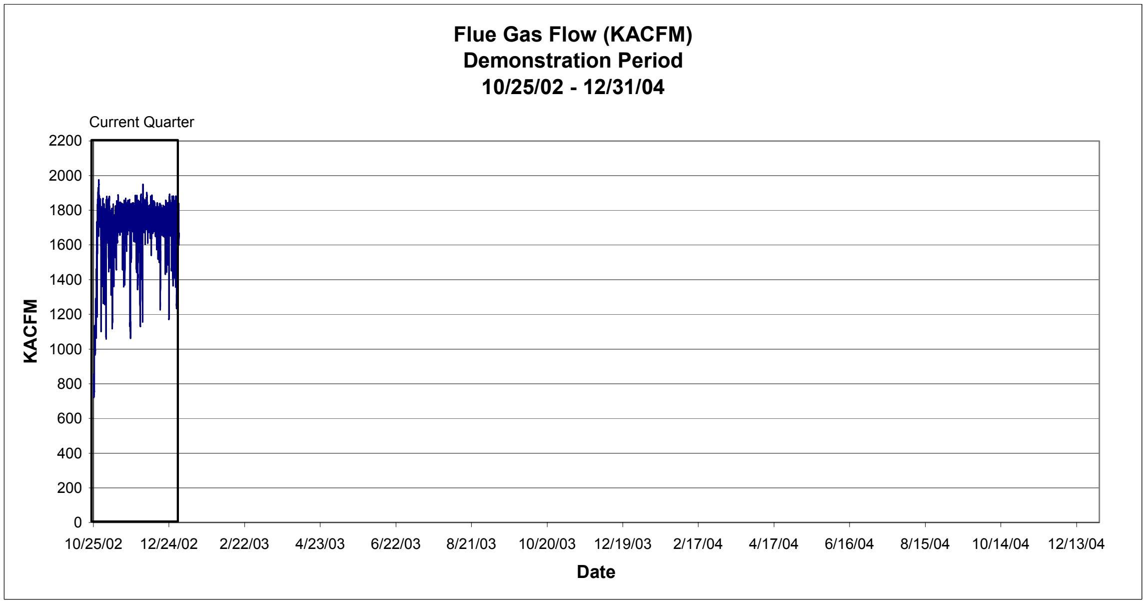


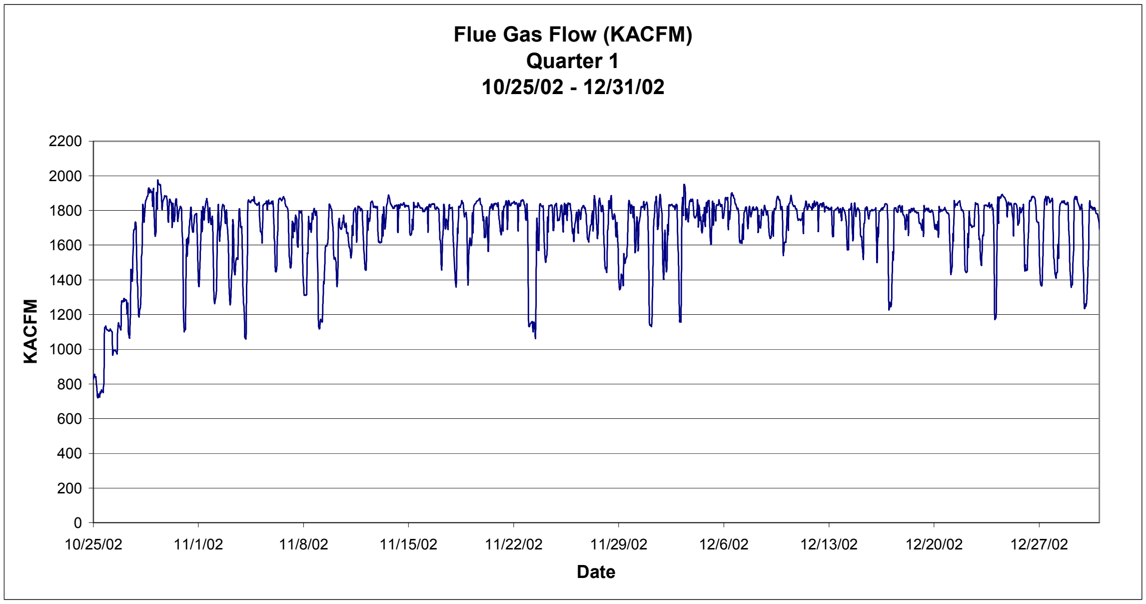
B2 Flue Gas Flow (KSCFM)



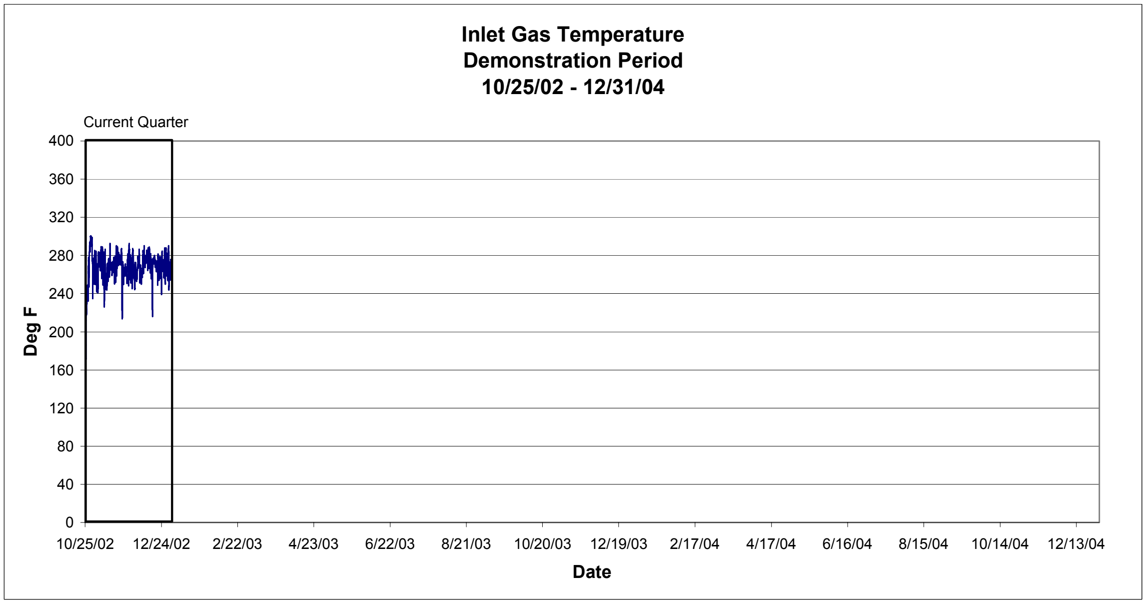


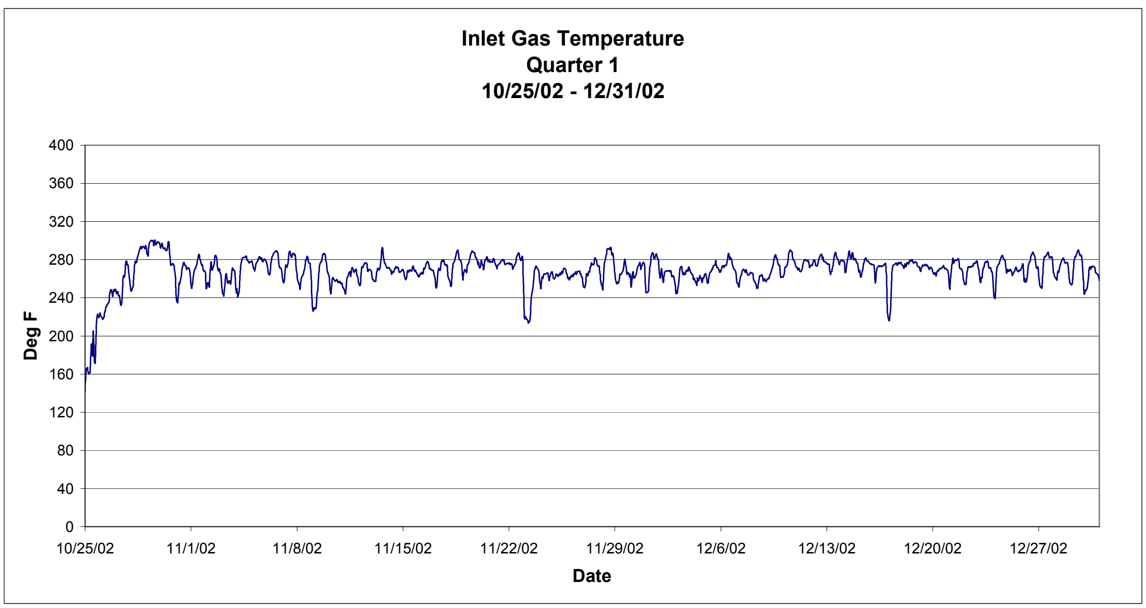
B3 Flue Gas Flow (KACFM)



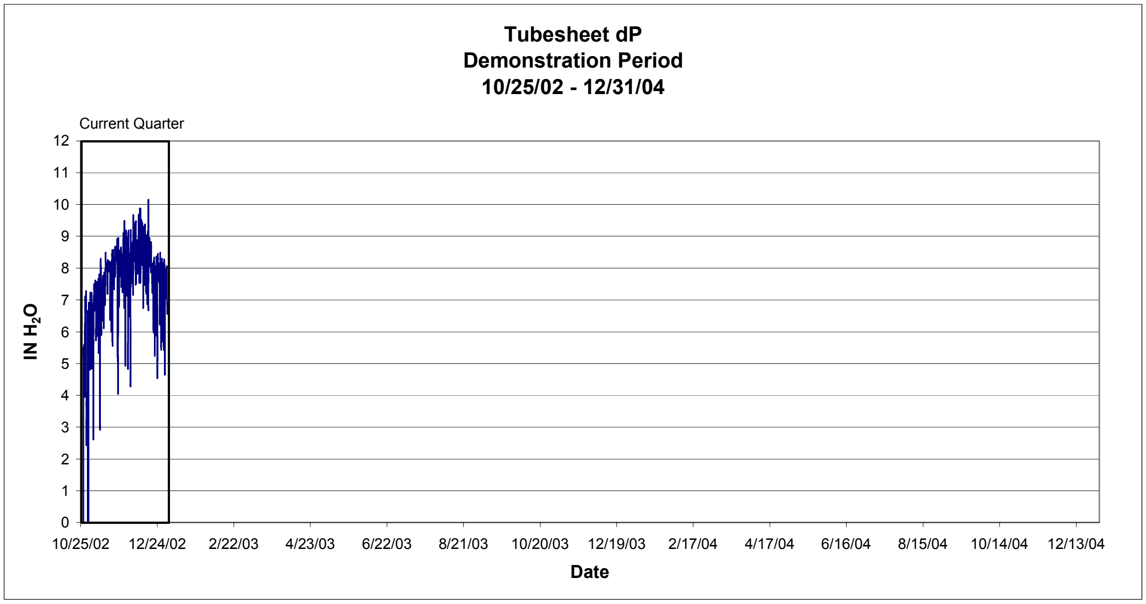


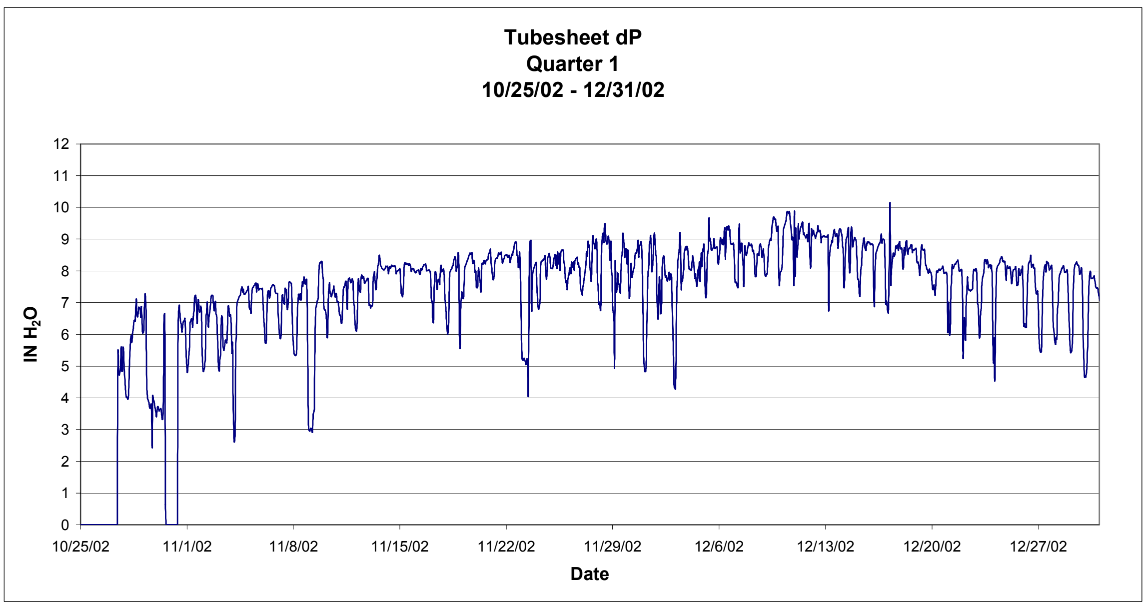
B4 Inlet Gas Temperature



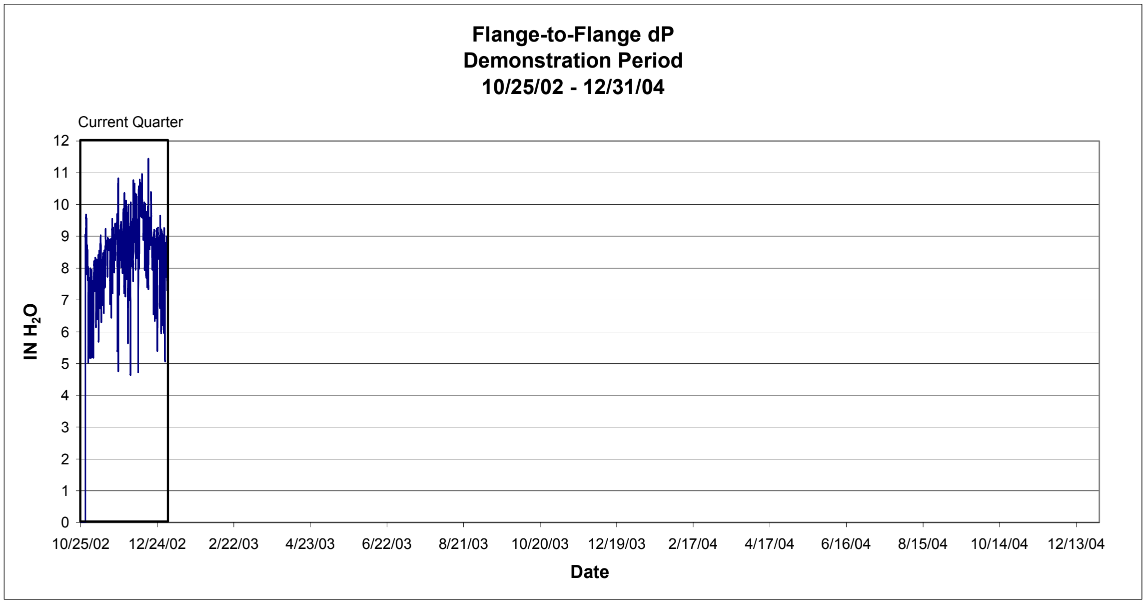


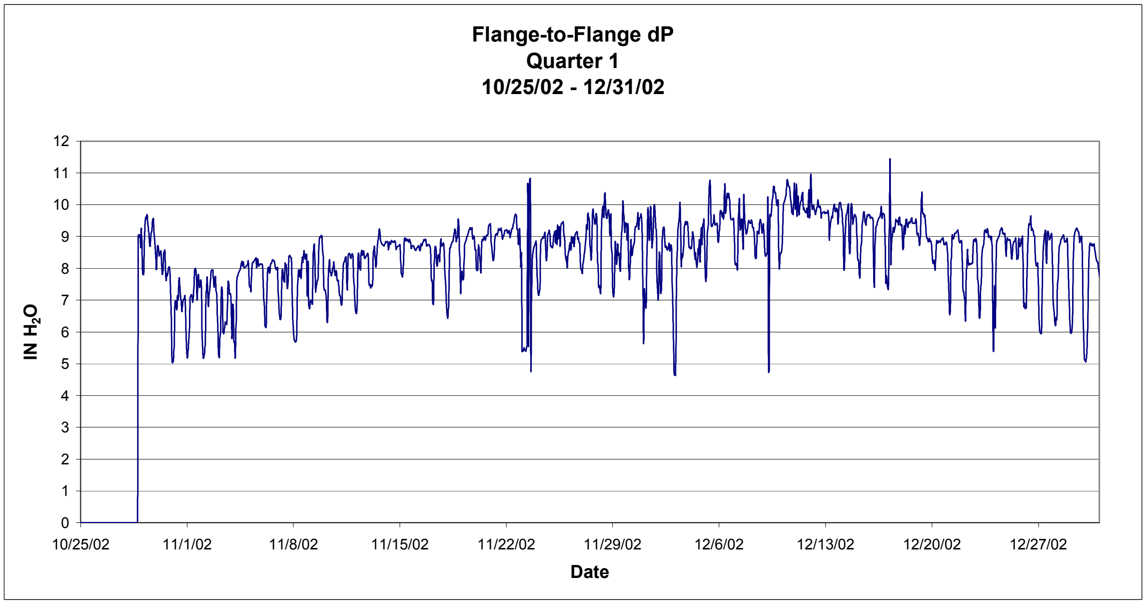
B5 Tubesheet dP



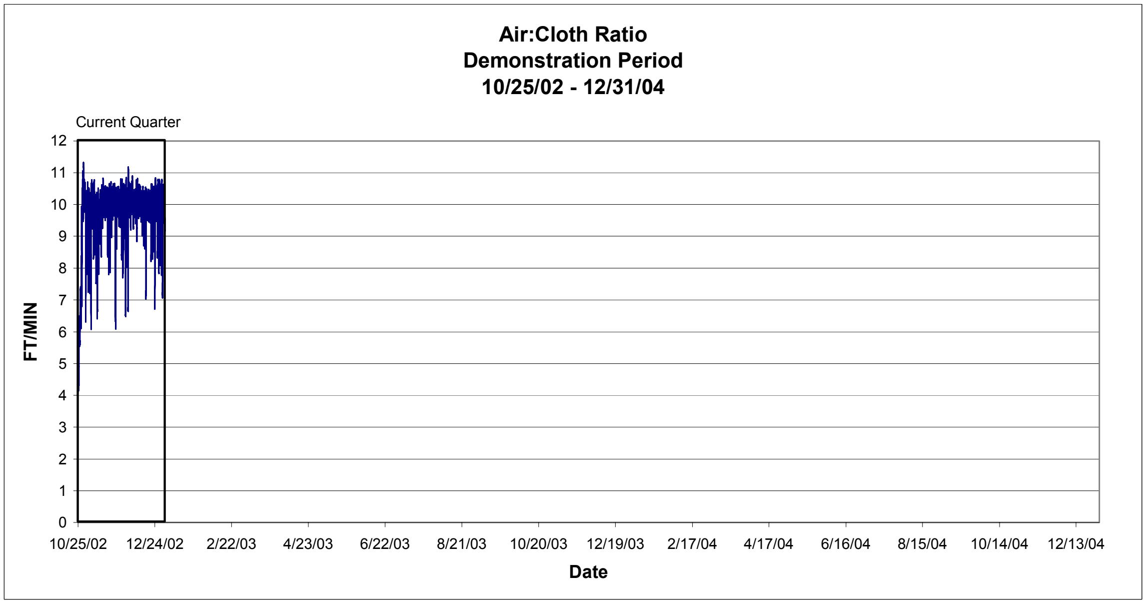


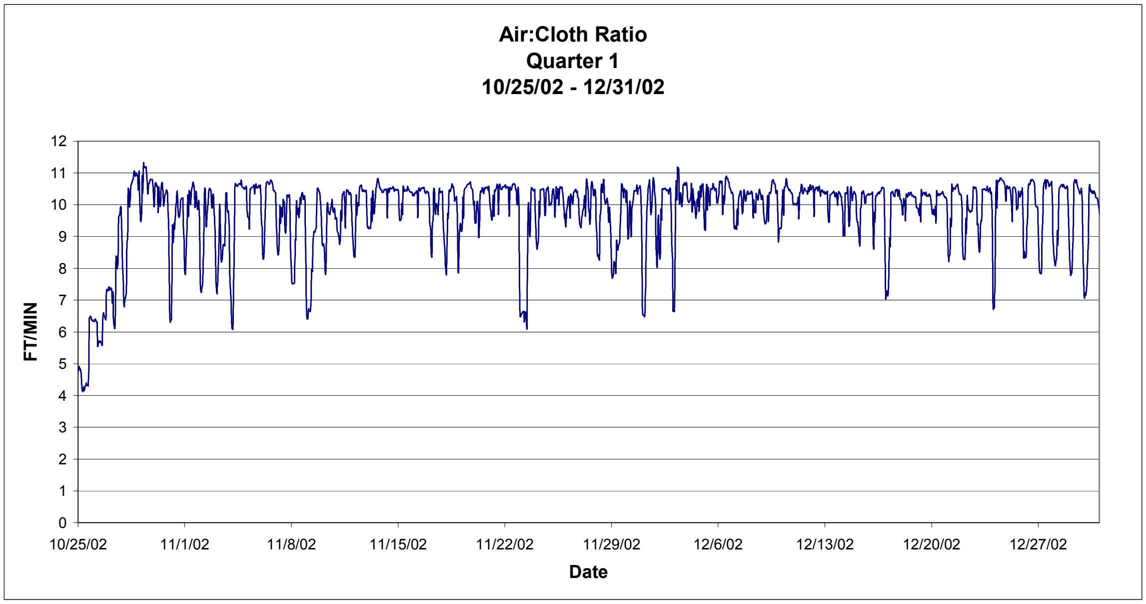
B6 Flange-to-Flange dP



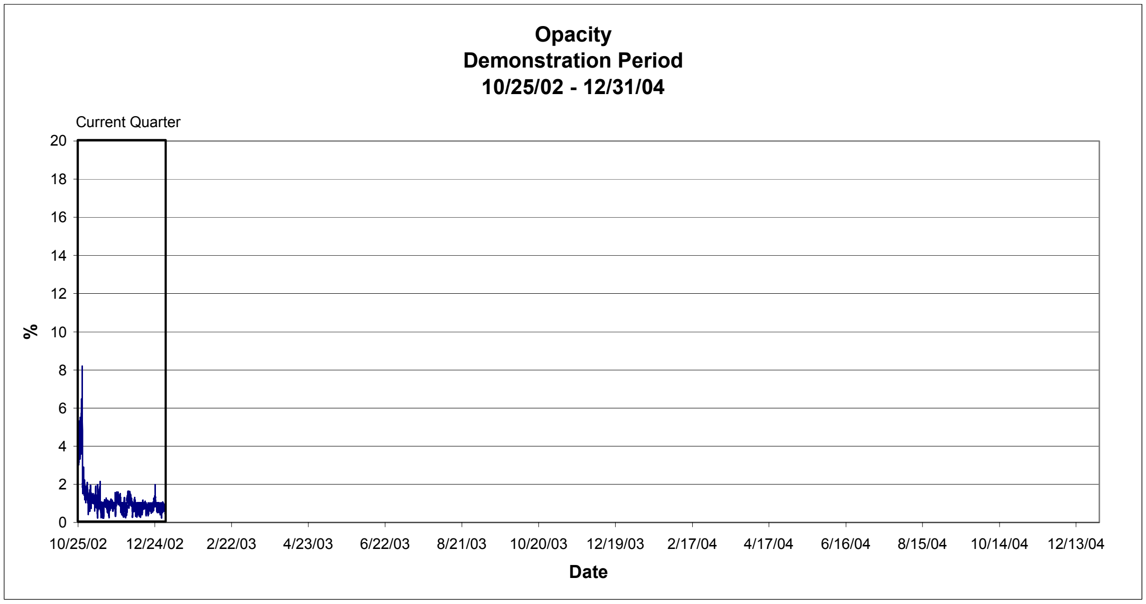


B7 Air-to-Cloth Ratio

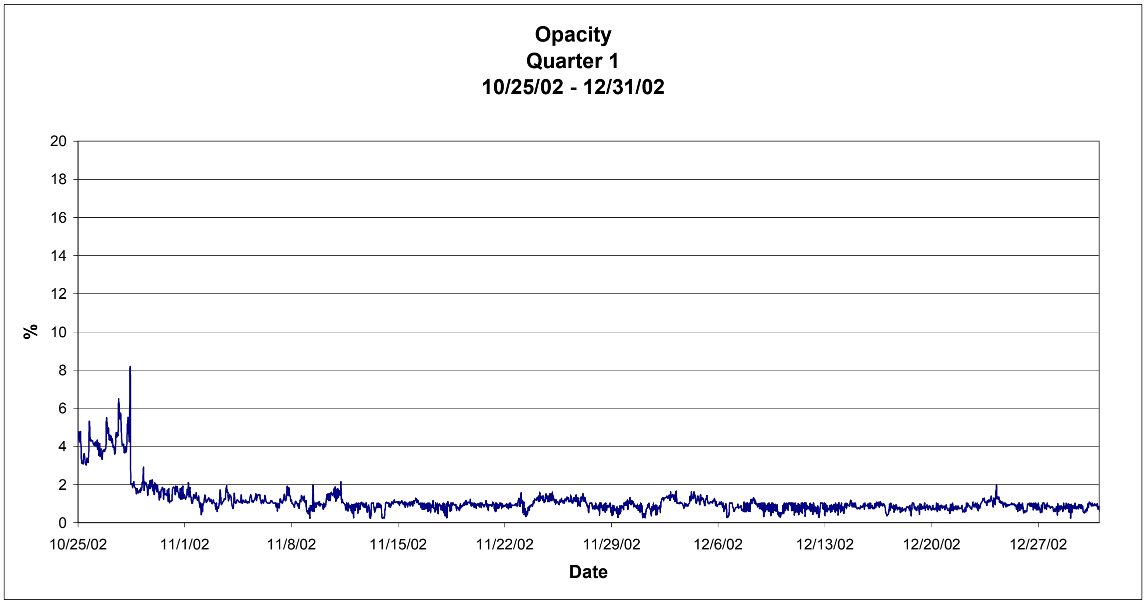




B8 Opacity

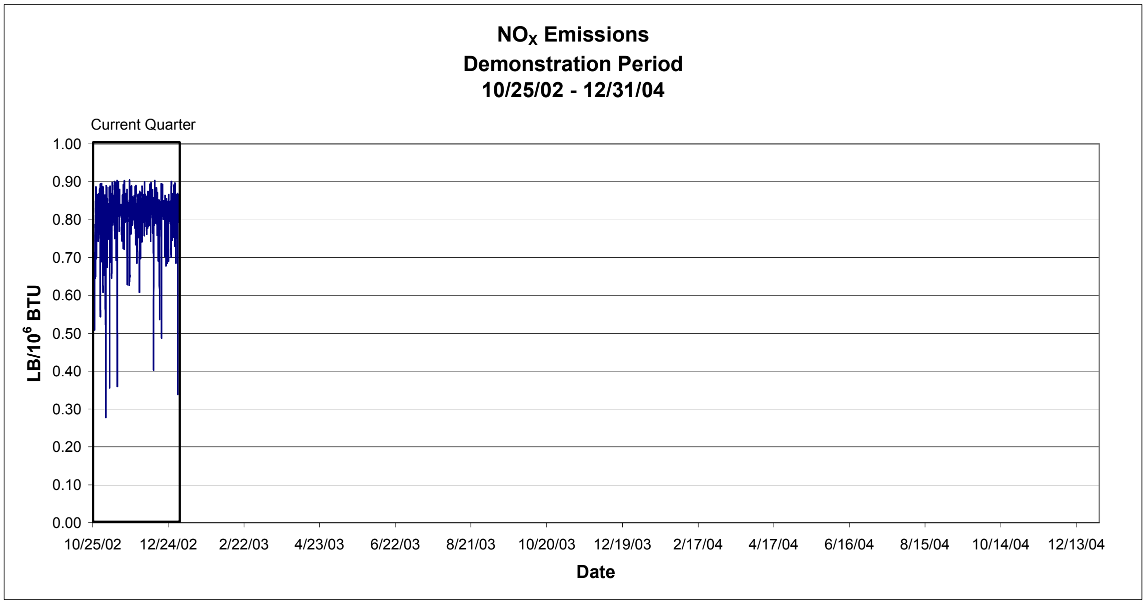


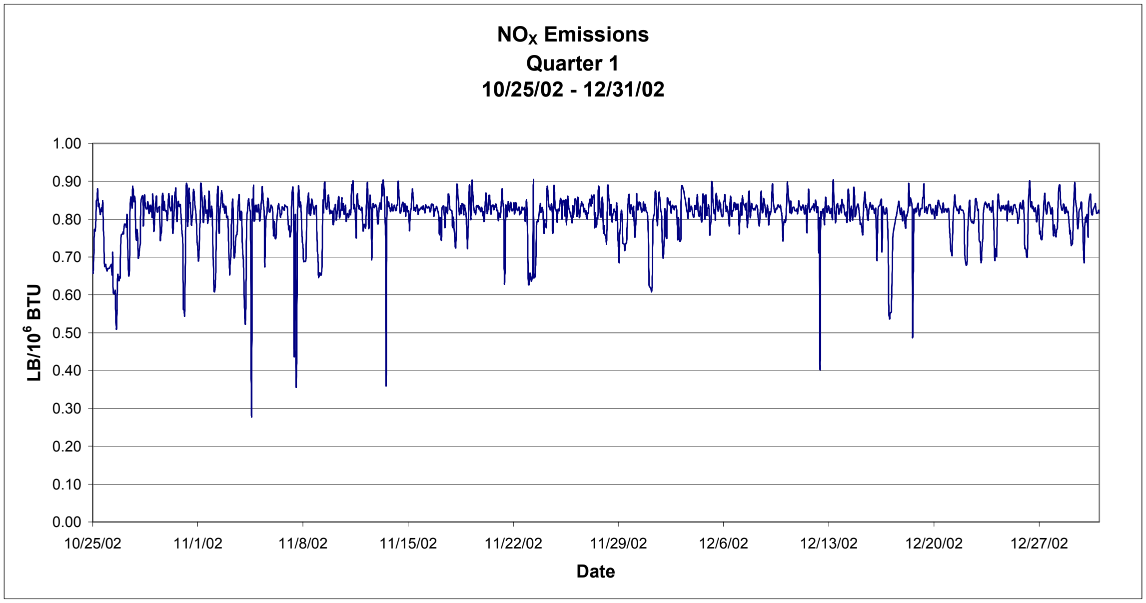
Opacity
Demonstration Period
10/25/02 - 12/31/04
Current Quarter
20
18
16
14
12
10
8
6
4
2
0
%
10/25/02
12/24/02
2/22/03
4/23/03
6/22/03
8/21/03
10/20/03
12/19/03
2/17/04
4/17/04
6/16/04
8/15/04
10/14/04
12/13/04
Date



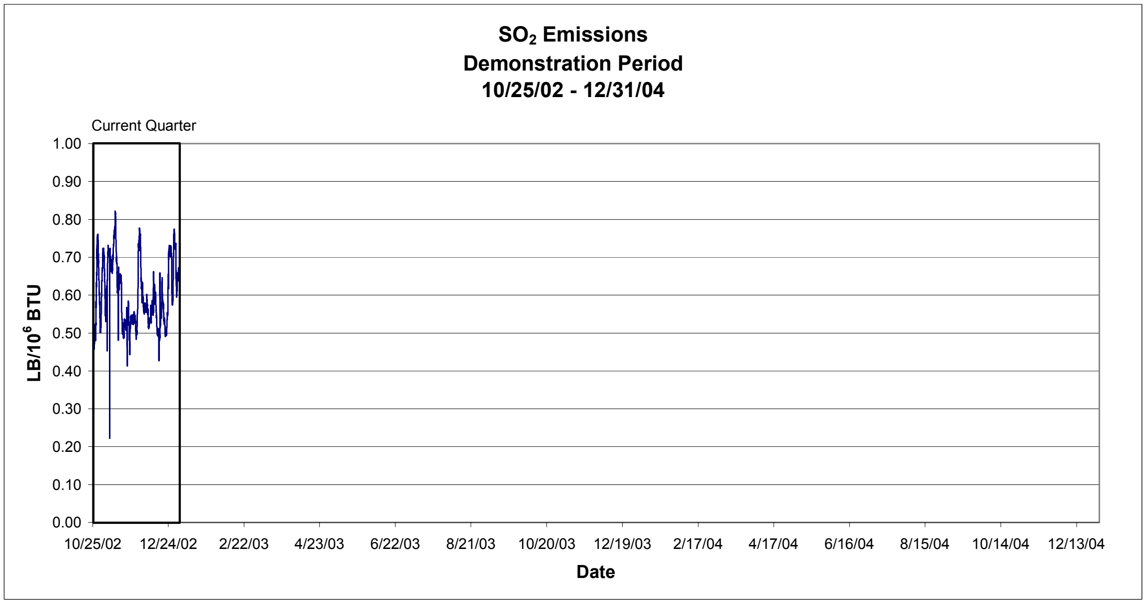
Opacity
Quarter 1
10/25/02 - 12/31/02
20
18
16
14
12
10
8
6
4
2
0
%
10/25/02
11/1/02
11/8/02
11/15/02
11/22/02
11/29/02
12/6/02
12/13/02
12/20/02
12/27/02
Date

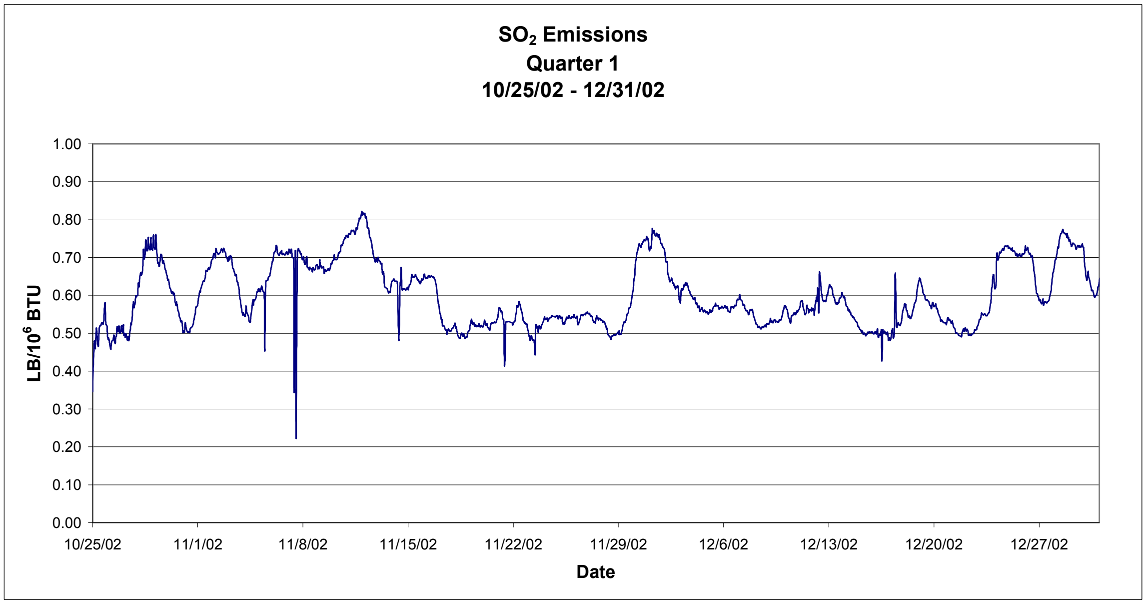
B9 NO_X Emissions



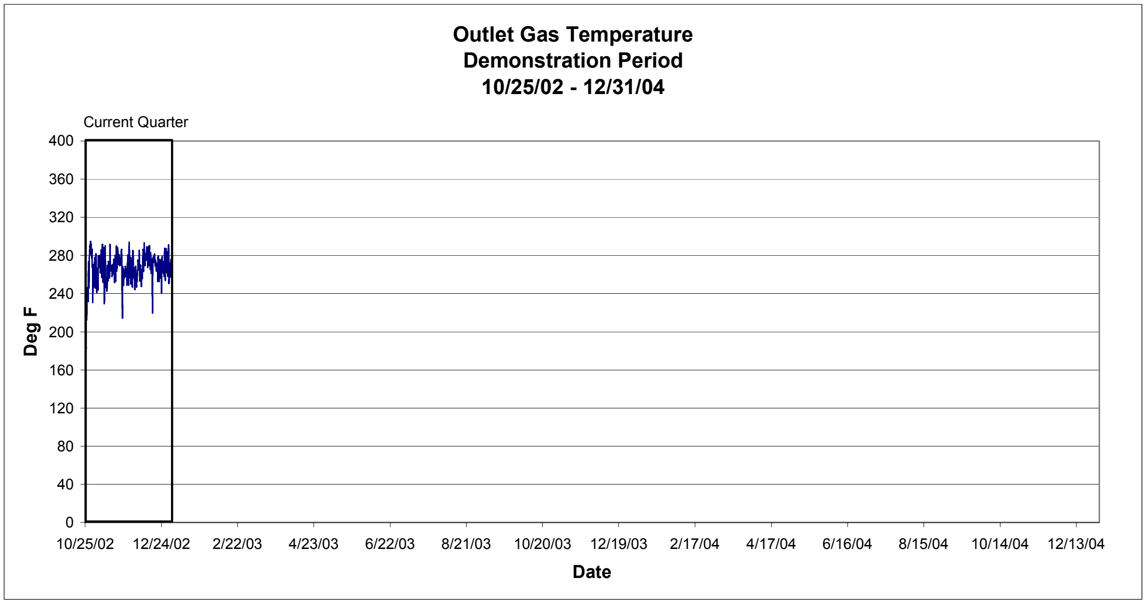


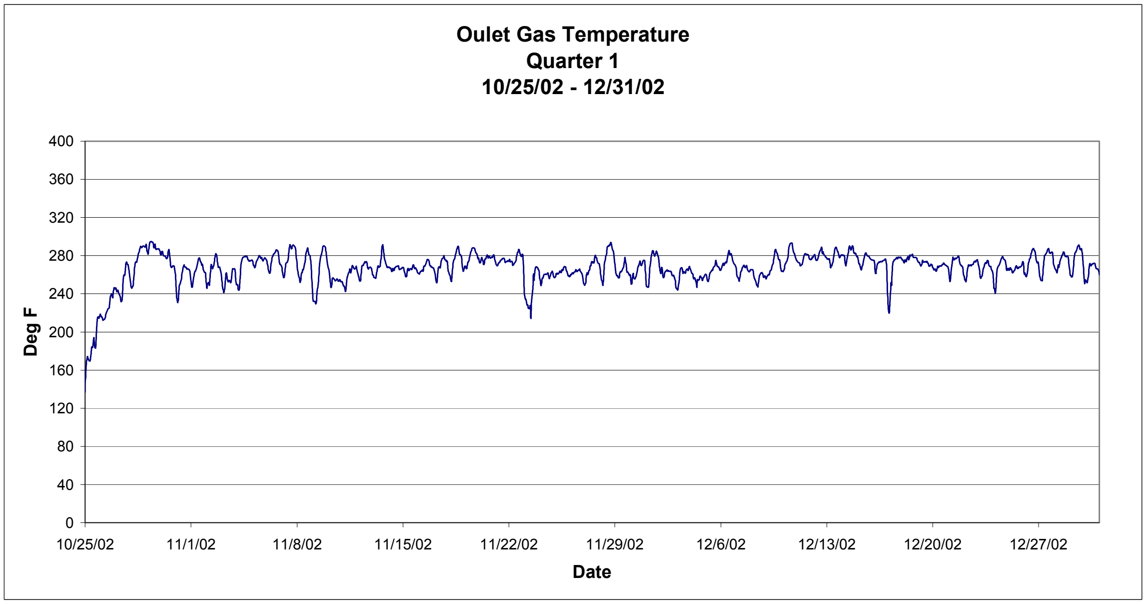
B10 SO_2 Emissions



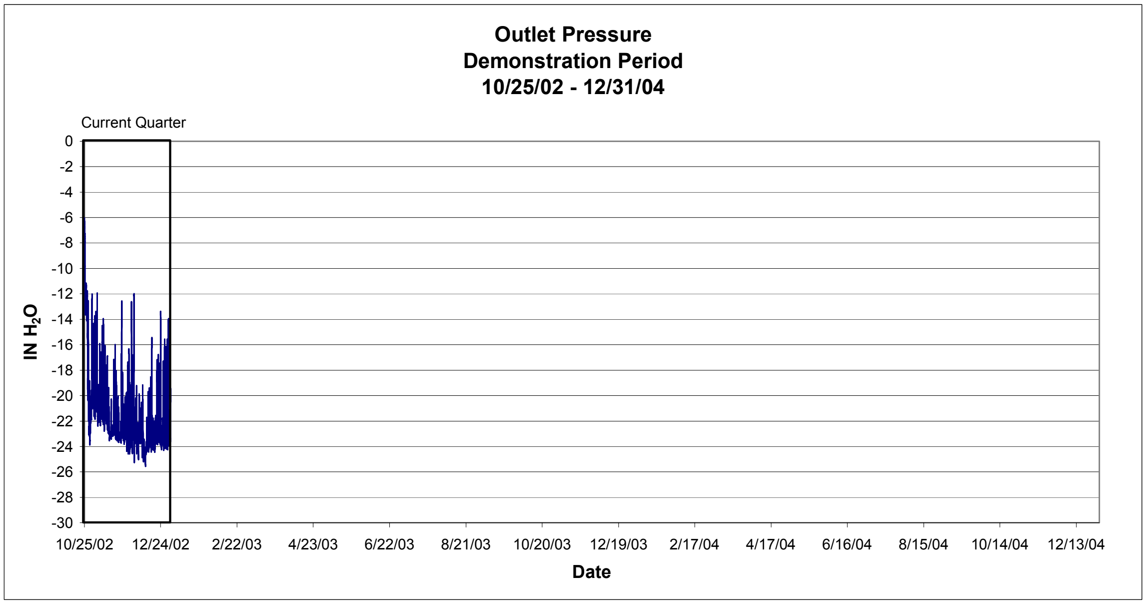


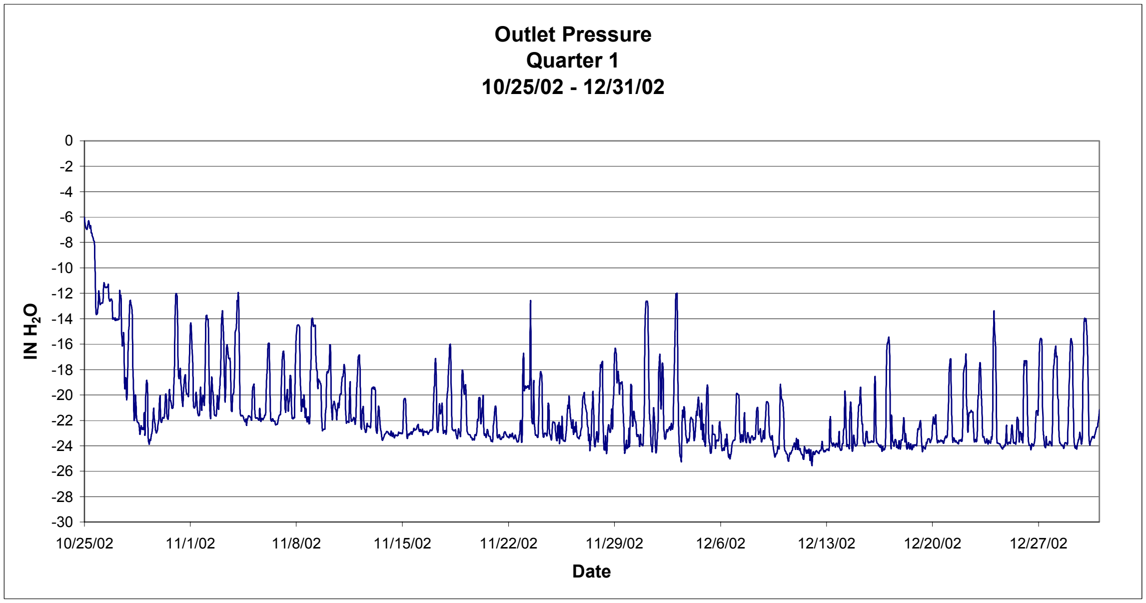
B11 Outlet Gas Temperature



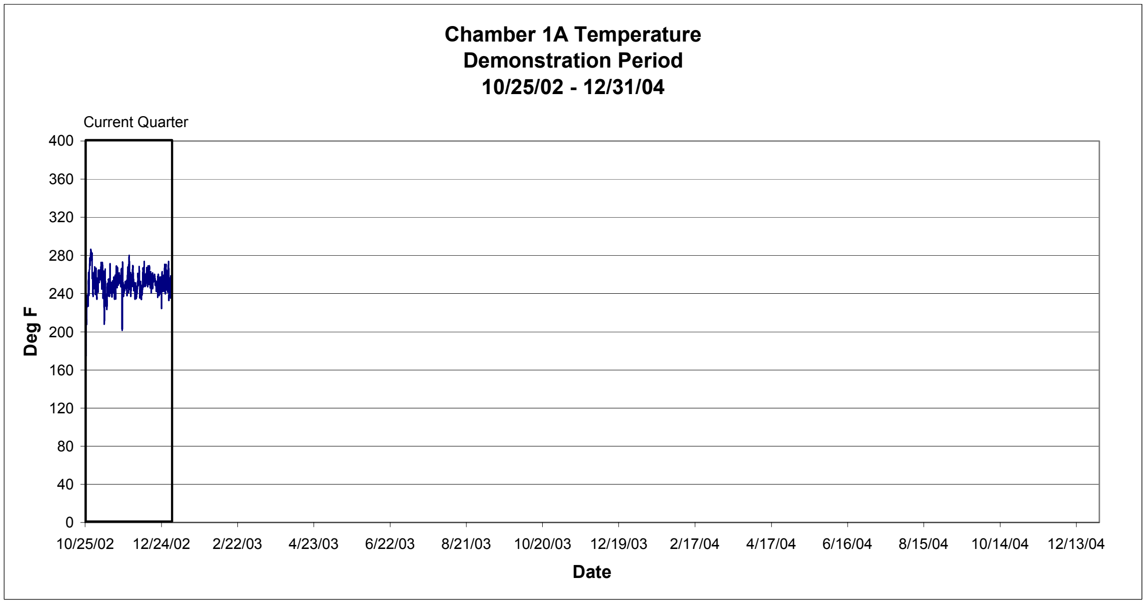


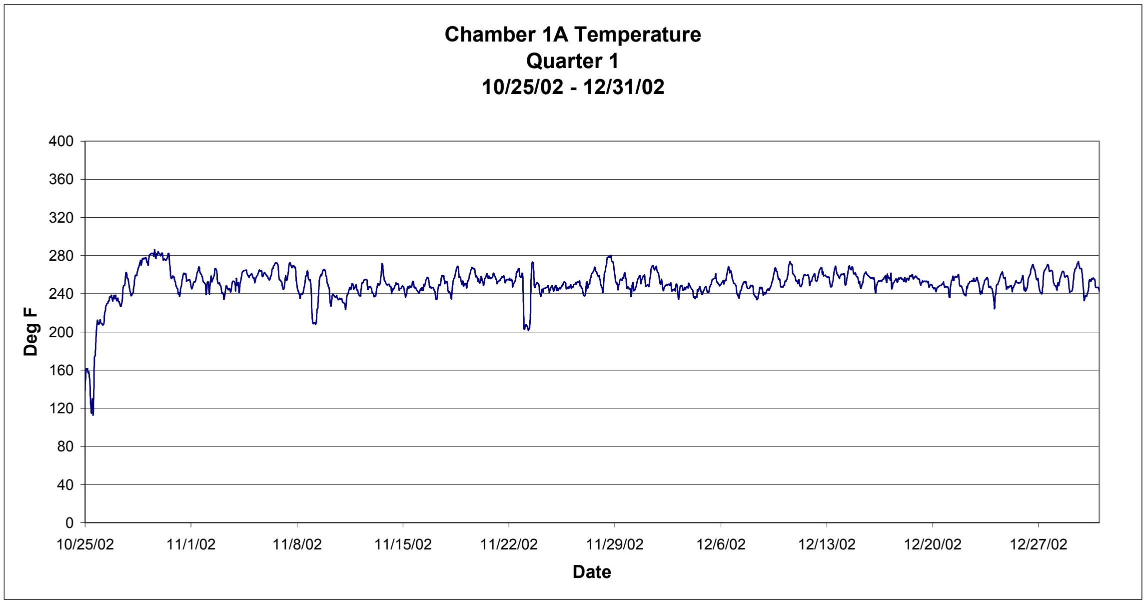
B12 Outlet Pressure

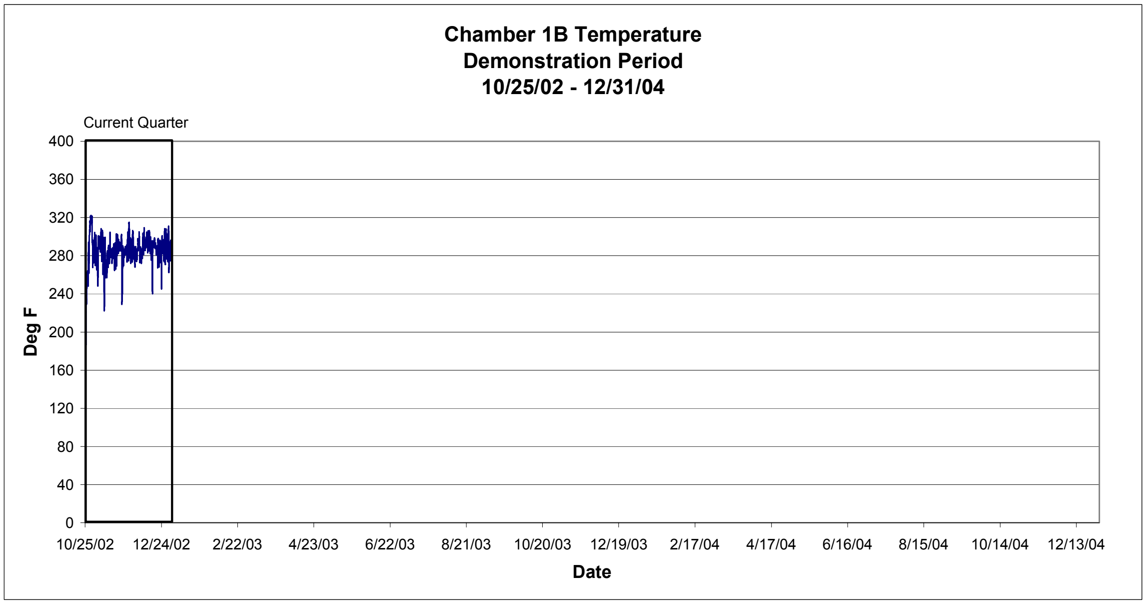


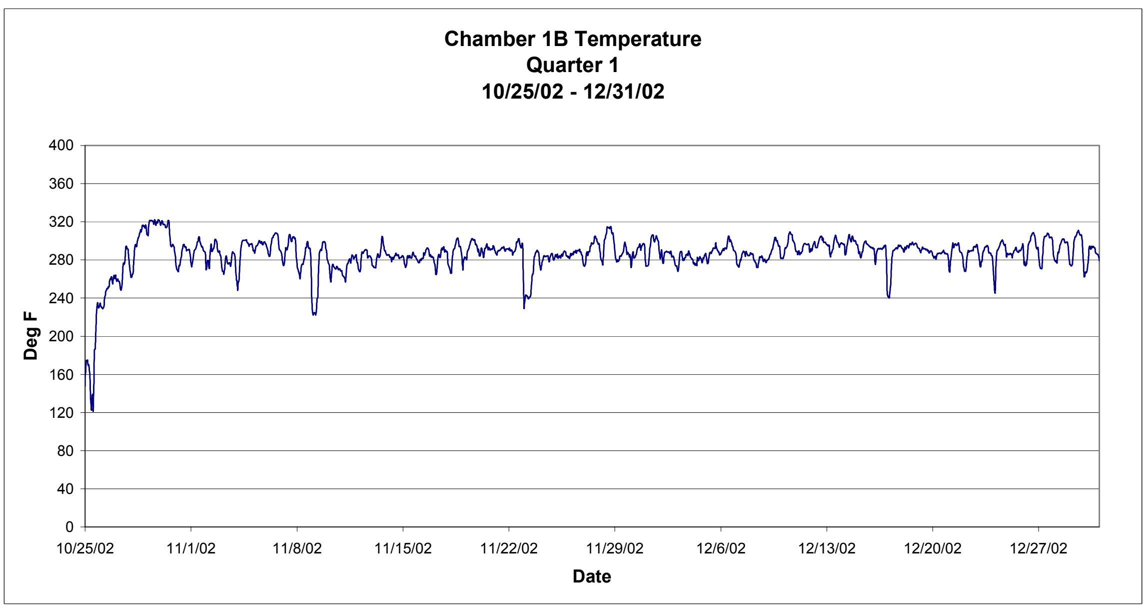


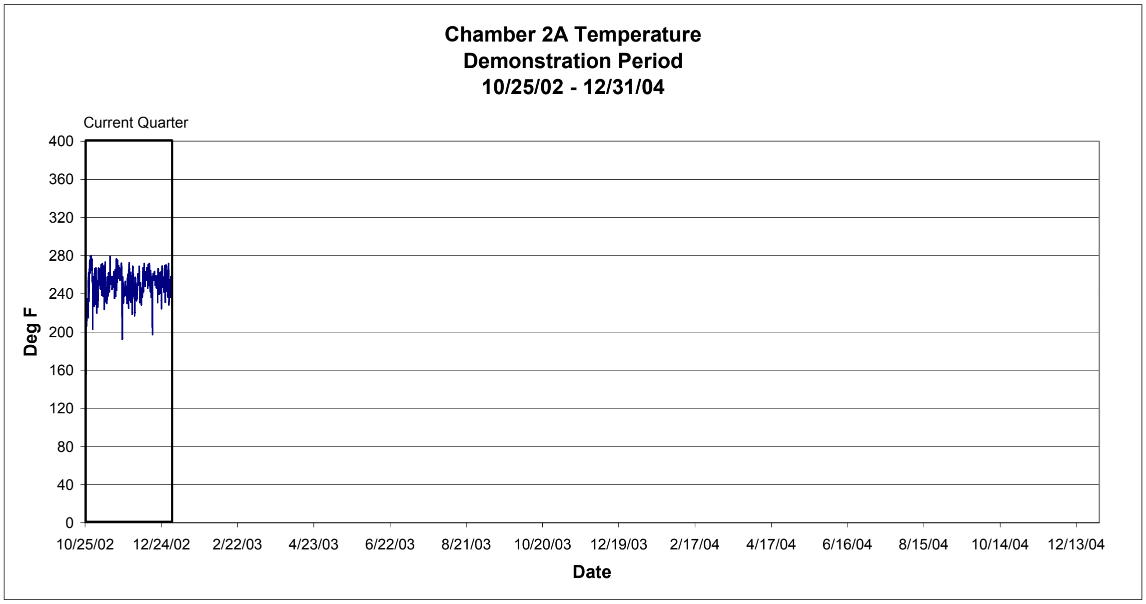
B13 Temperature per Chamber



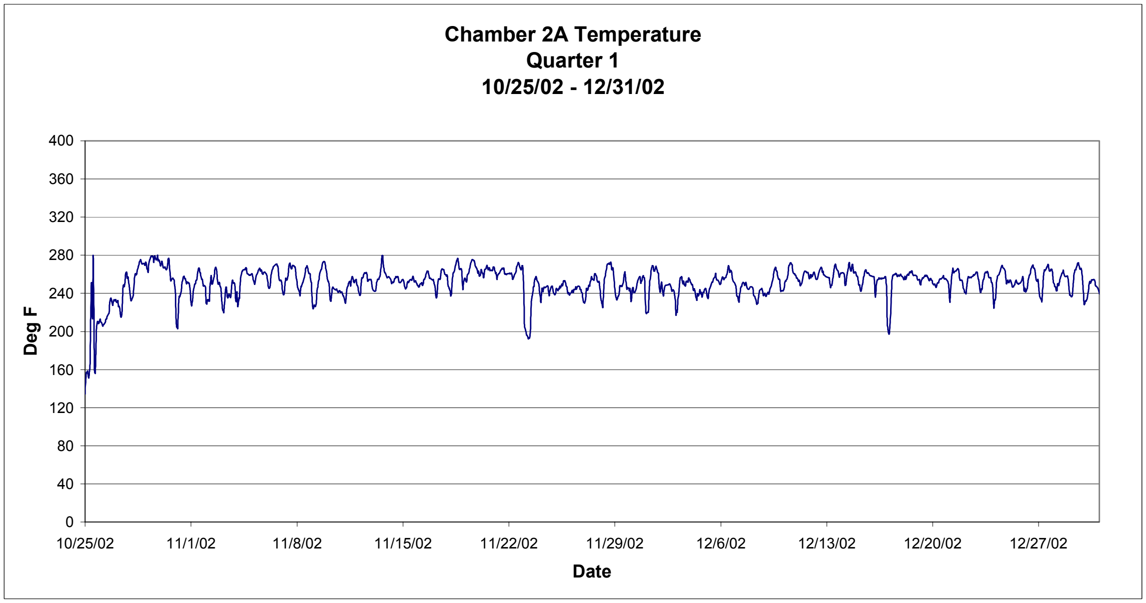



Chamber 1B Temperature
Demonstration Period
10/25/02 - 12/31/04
Current Quarter
Deg F
0
40
80
120
160
200
240
280
320
360
400
10/25/02
12/24/02
2/22/03
4/23/03
6/22/03
8/21/03
10/20/03
12/19/03
2/17/04
4/17/04
6/16/04
8/15/04
10/14/04
12/13/04
Date

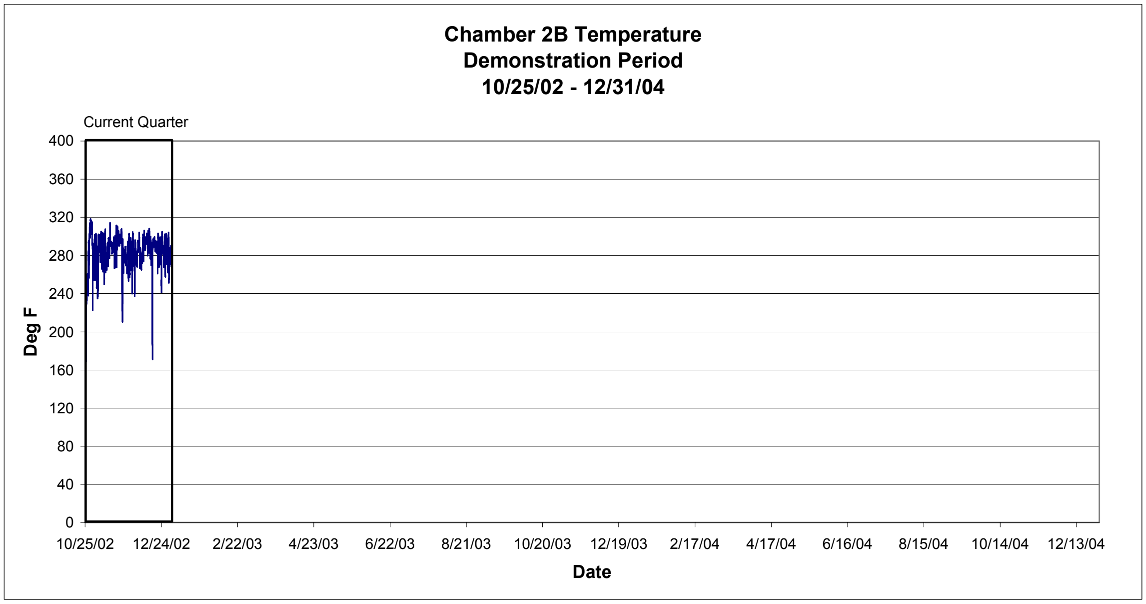

Chamber 1B Temperature
Quarter 1
10/25/02 - 12/31/02
Deg F
0
40
80
120
160
200
240
280
320
360
400
10/25/02
11/1/02
11/8/02
11/15/02
11/22/02
11/29/02
12/6/02
12/13/02
12/20/02
12/27/02
Date

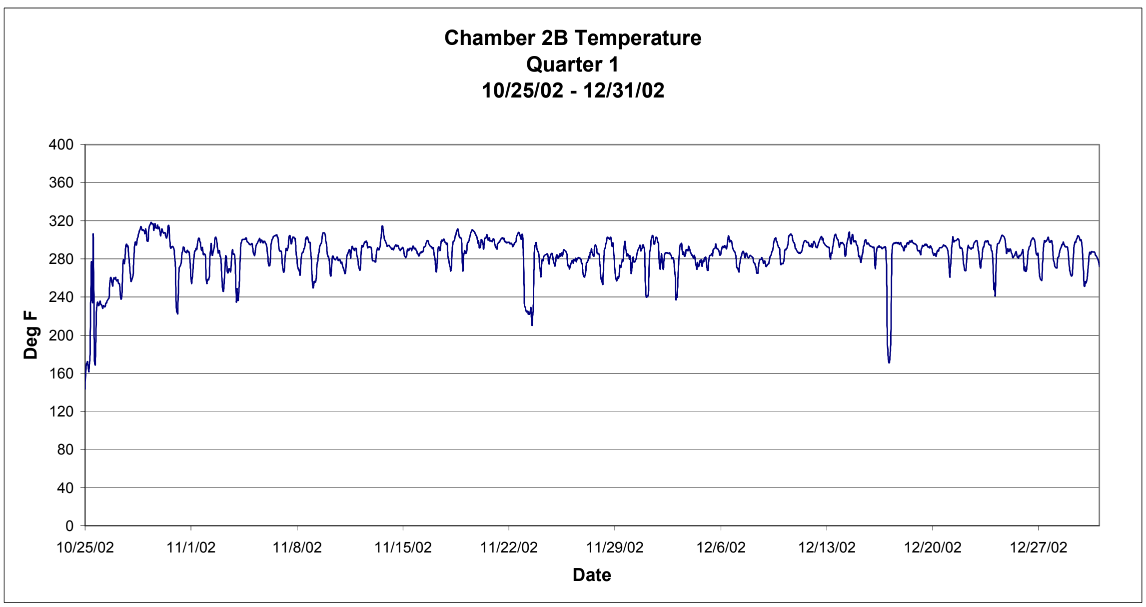


Chamber 2A Temperature
Demonstration Period
10/25/02 - 12/31/04
Current Quarter
Deg F
400
360
320
280
240
200
160
120
80
40
0
10/25/02
12/24/02
2/22/03
4/23/03
6/22/03
8/21/03
10/20/03
12/19/03
2/17/04
4/17/04
6/16/04
8/15/04
10/14/04
12/13/04
Date



Chamber 2A Temperature
Quarter 1
10/25/02 - 12/31/02
Deg F
400
360
320
280
240
200
160
120
80
40
0
10/25/02
11/1/02
11/8/02
11/15/02
11/22/02
11/29/02
12/6/02
12/13/02
12/20/02
12/27/02
Date


Chamber 2B Temperature
Demonstration Period
10/25/02 - 12/31/04
Current Quarter
Deg F
0
40
80
120
160
200
240
280
320
360
400
10/25/02
12/24/02
2/22/03
4/23/03
6/22/03
8/21/03
10/20/03
12/19/03
2/17/04
4/17/04
6/16/04
8/15/04
10/14/04
12/13/04
Date


Chamber 2B Temperature
Quarter 1
10/25/02 - 12/31/02
Deg F
0
40
80
120
160
200
240
280
320
360
400
10/25/02
11/1/02
11/8/02
11/15/02
11/22/02
11/29/02
12/6/02
12/13/02
12/20/02
12/27/02
Date

B14 Fuel Burn Record

BIG STONE PLANT
FUEL BURN RECORD
Oct-02

DATE	Coal	P. Coke	TDF	Waste Seeds	Toner	Gran. Insul.	Canvas Belting	Plastic Chips
	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)
1-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23-Oct-02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24-Oct-02	24.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25-Oct-02	1,245.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26-Oct-02	3,534.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27-Oct-02	5,058.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28-Oct-02	5,969.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29-Oct-02	6,442.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30-Oct-02	6,363.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31-Oct-02	5,619.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Adjustment	0.00							
Total Burned	34,257.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Delivered	56,477.36	0.00	22.39	189.33	0.00	0.00	0.00	0.00
HHV	8538	0	15000	7187	0	0	0	0
% Ash	4.41%	0.00%	7.04%	1.10%	0.00%	0.00%	0.00%	0.00%
Tons Ash	1,511.61	0.00	51.48	12.52	0.00	0.00	0.00	0.00

BIG STONE PLANT
FUEL BURN RECORD
Nov-02

DATE	Coal	P. Coke	TDF	Waste Seeds	Toner	Gran. Insul.	Canvas Belting	Plastic Chips
	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)
1-Nov-02	5,987.98	0.00	22.39	189.33	0.00	0.00	0.00	0.00
2-Nov-02	6,001.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3-Nov-02	5,640.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4-Nov-02	4,601.40	0.00	90.01	979.79	0.00	0.00	0.00	0.00
5-Nov-02	5,871.32	0.00	22.61	36.17	0.00	0.00	0.00	0.00
6-Nov-02	6,181.69	0.00	45.36	47.65	0.00	0.00	0.00	0.00
7-Nov-02	6,062.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8-Nov-02	5,518.75	0.00	249.68	98.17	0.00	0.00	0.00	0.00
9-Nov-02	5,418.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-Nov-02	6,080.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11-Nov-02	6,315.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12-Nov-02	6,169.84	0.00	45.18	24.18	0.00	0.00	0.00	0.00
13-Nov-02	6,139.55	0.00	91.71	23.04	0.00	0.00	0.00	0.00
14-Nov-02	6,305.74	0.00	117.44	48.82	0.00	0.00	0.00	0.00
15-Nov-02	6,202.35	0.00	46.40	84.85	0.00	0.00	0.00	0.00
16-Nov-02	6,510.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17-Nov-02	6,185.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18-Nov-02	5,796.69	0.00	43.73	160.38	0.00	0.00	0.00	0.00
19-Nov-02	6,013.24	0.00	22.87	194.89	0.00	0.00	0.00	0.00
20-Nov-02	6,289.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21-Nov-02	6,364.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22-Nov-02	6,037.07	0.00	139.47	179.66	0.00	0.00	0.00	0.00
23-Nov-02	4,780.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24-Nov-02	6,275.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25-Nov-02	6,341.81	0.00	22.79	0.00	26.60	0.00	0.00	0.00
26-Nov-02	6,248.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27-Nov-02	6,151.53	0.00	0.00	78.47	0.00	0.00	0.00	0.00
28-Nov-02	5,913.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29-Nov-02	5,651.60	0.00	45.50	0.00	0.00	0.00	0.00	0.00
30-Nov-02	6,338.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Adjustment	5,000.00							
Total Burned	184,394.76	0.00	1,005.14	2,145.40	26.60	0.00	0.00	0.00
Total Delivered	193,968.54	0.00	982.75	1,956.07	26.60	0.00	0.00	0.00
HHV	8534	0	15000	7187	16932	0		
% Ash	4.73%	0.00%	7.04%	1.10%	0.00%	0.00%		
Tons Ash	8,715.21	0.00	70.76	23.60	0.00	0.00	0.00	0.00

BIG STONE PLANT
FUEL BURN RECORD - page 1 of 3
Dec-02

DATE	Coal	P. Coke	TDF	Waste Seeds	Toner	Gran. Insul.	Canvas Belting	Plastic Chips
	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)	(Tons)
1-Dec-02	5,707.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2-Dec-02	6,179.46	0.00	46.14	0.00	0.00	0.00	0.00	0.00
3-Dec-02	5,916.85	0.00	43.80	97.85	0.00	0.00	0.00	0.00
4-Dec-02	6,348.34	0.00	22.26	0.00	0.00	0.00	0.00	0.00
5-Dec-02	6,340.69	0.00	20.11	0.00	0.00	0.00	0.00	0.00
6-Dec-02	6,484.34	0.00	46.06	0.00	0.00	0.00	0.00	0.00
7-Dec-02	6,378.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8-Dec-02	6,530.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9-Dec-02	6,317.27	0.00	43.53	0.00	0.00	0.00	0.00	0.00
10-Dec-02	6,267.33	0.00	45.67	26.00	0.00	0.00	0.00	0.00
11-Dec-02	6,394.00	0.00	94.30	0.00	0.00	0.00	0.00	0.00
12-Dec-02	6,523.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13-Dec-02	6,257.51	0.00	93.99	0.00	0.00	0.00	0.00	0.00
14-Dec-02	6,373.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15-Dec-02	6,351.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16-Dec-02	6,274.49	0.00	70.37	17.64	0.00	0.00	0.00	0.00
17-Dec-02	5,785.53	0.00	45.77	0.00	0.00	0.00	0.00	0.00
18-Dec-02	6,368.68	0.00	47.44	47.88	0.00	0.00	0.00	0.00
19-Dec-02	6,374.26	0.00	24.14	48.00	0.00	0.00	0.00	0.00
20-Dec-02	6,453.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21-Dec-02	6,289.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22-Dec-02	6,072.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23-Dec-02	6,171.47	0.00	64.61	71.82	0.00	0.00	0.00	0.00
24-Dec-02	6,183.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25-Dec-02	6,604.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26-Dec-02	6,236.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27-Dec-02	6,056.94	0.00	44.89	25.47	0.00	0.00	0.00	0.00
28-Dec-02	6,240.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29-Dec-02	6,168.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30-Dec-02	5,950.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31-Dec-02	5,951.26	0.00	116.11	75.03	0.00	0.00	0.00	0.00
Adjustment	3,000.00							
Total Burned	196,553.92	0.00	869.19	409.69	0.00	0.00	0.00	0.00
Total Delivered	195,368.84		869.19	409.69	0.00			0.00
HHV	8533		15000	7187	0	0		
% Ash	4.71%		7.04%	1.10%	0.00%	0.00%		
Tons Ash	9,254.39	0.00	70.76	23.60	0.00	0.00	0.00	0.00

B15 Fuel Analysis Record

BIG STONE PLANT	COAL ANALYSIS PER TRAIN
	Oct-02

DATE	TR #	MOIS. %	% ASH AR	HHV AR	S, % AR	% ASH DRY	HHV DRY	S, % DRY	NaO %	MAF HHV	COAL TONS	TONS OK
PREV. MON.												
PREV. MON.												
1-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
2-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
3-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
4-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
5-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
6-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
7-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
8-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
9-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
10-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
11-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
12-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
13-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
14-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
15-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
16-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
17-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
18-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
19-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
20-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
21-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
22-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
23-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
24-Oct-02	bam75	29.59	4.15	8639	0.27	5.9	12269	0.39	1.49	13038	13008.930	13008.930
25-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
26-Oct-02	ebm33	30.44	4.79	8404	0.38	6.89	12081	0.55	1.9	12975	14158.850	14158.850
27-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
28-Oct-02	bam76	29.63	4.14	8618	0.26	5.88	12247	0.37	1.42	13012	14061.250	7090.020
29-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
30-Oct-02	0	0	0	0	0	0	0	0	0	0	0.000	
31-Oct-02	ebm34	29.98	4.87	8462	0.41	6.96	12085	0.59	1.86	12989	12962.025	
ADJ.												34257.800
											Tons. OK	34257.800
Weighted Average		29.95	4.41	8538	0.31	6.31	12187	0.45	1.64		Burn	34257.800

Monthly Mercury Analysis

Train #	Sample #	% Moist.	Mercury ug/g dry basis	Chlor. ug/g

BIG STONE PLANT	COAL ANALYSIS PER TRAIN
	Nov-02

DATE	TR #	MOIS. %	% ASH AR	HHV AR	S, % AR	% ASH DRY	HHV DRY	S, % DRY	NaO %	MAF HHV	COAL TONS	TONS OK
PREV. MON	bam76	29.63	4.14	8618	0.26	5.88	12247	0.37	1.4	13012	14061.25	10256.72
PREV. MON	ebm34	29.98	4.87	8462	0.41	6.96	12085	0.59	1.86	12989	12962.03	12962.03
1-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	
2-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	
3-Nov-02	crm01	30.09	5.03	8464	0.32	5.03	12106	0.46	1.1	13045	14143.18	14143.18
4-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	0.00
5-Nov-02	ebm35	30.36	4.75	8429	0.38	6.82	12103	0.54	1.9	12989	12205.48	12205.48
6-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	0.00
7-Nov-02	cdm01	28.79	5.93	8501	0.34	8.32	11939	0.41	1.3	13023	12960.60	12960.60
8-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	0.00
9-Nov-02	ebm36	29.86	4.83	8479	0.39	6.88	12088	0.56	1.8	12981	14098.98	14098.98
10-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	0.00
11-Nov-02	bam 77	29.51	4.88	8512	0.3	6.93	12076	0.42	1.4	12975	12795.68	12795.68
12-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	0.00
13-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	0.00
14-Nov-02	bam78	29.8	4.75	8589	0.31	6.76	12235	0.44	1.4	13122	14128.18	14128.18
15-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	0.00
16-Nov-02	bam79	29.86	4.1	8601	0.27	5.85	12262	0.38	1.6	13024	14043.63	14043.63
17-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	0.00
18-Nov-02	bam80	29.36	4.53	8629	0.29	6.41	12215	0.41	1.5	13052	13470.35	13470.35
19-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	0.00
20-Nov-02	bam81	29.53	4.64	8549	0.28	6.58	12132	0.4	1.4	12987	13204.80	13204.80
21-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	0.00
22-Nov-02	bam82	29.85	4.74	8466	0.29	6.75	12069	0.41	1.4	12943	14150.85	14150.85
23-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	0.00
24-Nov-02	bam83	29.29	4.46	8641	0.3	6.31	12221	0.42	1.5	13044	12727.63	12727.63
25-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	
26-Nov-02	bam84	29.72	4.41	8560	0.25	6.27	12180	0.36	1.5	12995	12724.88	12724.88
27-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	
28-Nov-02	ebm037	30.13	4.76	8456	0.42	6.81	12102	0.6	1.9	12986	13889.23	521.79
29-Nov-02	0	0	0	0	0	0	0	0	0	0	0.00	
30-Nov-02	crm02	29.37	5.62	8464	0.3	7.96	11982	0.42	1.2	13019	13825.90	
ADJ.												184394.76
											Tons. OK	184394.76
Weighted Average		29.69	4.73	8534	0.31	6.55	12139	0.44	1.50		Burn	184394.76

Monthly Mercury Analysis

Train #	Sample #	% Moist.	Mercury ug/g dry basis	Chlor. ug/g
	C2489	30.15	0.11	<0.01

BIG STONE PLANT	COAL ANALYSIS PER TRAIN
	Dec-02

DATE	TR #	MOIS %	% ASH AR	HHV AR	S, % AR	% ASH DRY	HHV DRY	S, % DRY	NaO %	MAF HHV	COAL TONS	TONS OK
PREV. MON	ebm037	30.13	4.76	8456	0.42	6.81	12102	0.60	1.92	12986	13889.23	13367.44
PREV. MON	crm02	29.37	5.62	8464	0.30	7.96	11982	0.42	1.17	13019	13825.90	13825.90
1-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
2-Dec-02	bam85	30.3	4.26	8530	0.29	6.11	12234	0.42	1.49	13030	10461.98	10461.98
3-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
4-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
5-Dec-02	crm03	30.8	5.21	8348	0.28	7.53	12055	0.4	1.21	13037	11797.38	11797.38
6-Dec-02	bam86	29.3	4.37	8658	0.25	6.18	12253	0.35	1.56	13060	14086.78	14086.78
7-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
8-Dec-02	bam87	29.9	4.53	8554	0.33	6.47	12205	0.47	1.43	13049	13267.00	13267.00
9-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
10-Dec-02	bam88	29.9	4.6	8565	0.29	6.57	12220	0.42	1.45	13079	14101.13	14101.13
11-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
12-Dec-02	bam89	29.4	4.32	8653	0.27	6.12	12255	0.38	1.49	13054	13264.00	13264.00
13-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
14-Dec-02	bam90	30.3	4.23	8537	0.26	6.07	12247	0.38	1.42	13038	14113.73	14113.73
15-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
16-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
17-Dec-02	bam91	29.1	4.56	8672	0.33	6.43	12225	0.46	1.44	13065	13722.10	13722.10
18-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
19-Dec-02	bam92	28.7	4.28	8729	0.26	6	12238	0.36	1.4	13019	14141.13	14141.13
20-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
21-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
22-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
23-Dec-02	ebm38	30.2	5	8396	0.37	7.17	12028	0.53	1.71	12957	14159.77	14159.77
24-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
25-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
26-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
27-Dec-02	ebm39	30.4	4.85	8381	0.4	6.97	12043	0.57	1.81	12945	13929.20	13929.20
28-Dec-02	0	0	0	0	0	0	0	0	0	0	0.00	
29-Dec-02	bam93	28.6	4.45	8712	0.31	6.24	12208	0.44	1.29	13020	14053.55	9182.78
30-Dec-02	ebm40	30	4.76	8457	0.42	6.79	12073	0.6	1.93	12952	13881.20	0.00
31-Dec-02	0	0	0	0	0	0	0	0	0	0	14145.23	
ADJ.												183420.32
											Tons. OK	196553.92
Weighted Average		29.78	4.71	8533	0.31	6.71	12151	0.44	1.49		Burn	196553.92

Monthly Mercury Analysis

Train #	Sample #	% Moist.	Mercury ug/g dry basis	Chlor. ug/g

B16 Ash Analysis Record

JAN.27.2003 11:25AM COMM/OPPT NO.323 P.3/4

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 1919 SOUTH HIGHLAND AVE., SUITE 210-B, LOMBARD, ILLINOIS 60148 • TEL: 630-953-9300 FAX: 630-953-9306

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January 10, 2003

RAG COAL WEST, INC.
EAGLE BUTTE MINE
P.O. BOX 3040
GILLETTE WY 82717

Sample identification by
RAG Coal West, Inc.

SAMPLE ID:	36-114564
TRAIN #:	BSB041
TOTAL TONNAGE:	14145.225
CUSTOMER:	OTTERTAIL POWER
PLANT:	BIG STONE
LOAD DATE:	12/31/2002

Kind of sample reported to us	COAL
Sample taken at	Eagle Butte
Sample taken by	Eagle Butte
Date sampled	December 31, 2002
Date received	January 10, 2003

Analysis report no. 44-59398

ANALYSIS OF ASH	% Weight Ignited Basis
Silica, SiO_2	29.92
Alumina, Al_2O_3	16.85
Titania, TiO_2	1.23
Ferric Oxide, Fe_2O_3	5.33
Lime, CaO	26.82
Magnesia, MgO	6.49
Potassium Oxide, K_2O	0.23
Sodium Oxide, Na_2O	1.81
Sulfur Trioxide, SO_3	11.00
Phosphorous Pentoxide, P_2O_5	0.59
Strontium Oxide, SrO	0.63
Barium Oxide, BaO	0.64
Manganese Oxide, Mn_3O_4	0.03
Undetermined	xxxxxx

Done
lo 1-24-03

Silica Value=	43.64
Base: Acid Ratio=	0.85
T_{250} Temperature=	2281 °F
Type of Ash=	LIGNITIC
Fouling Index=	1.81

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.

Connie Christiansen

Gillette Laboratory

MEMBER ACIL

F-465
Original Watermarked For Your Protection

TERMS AND CONDITIONS ON REVERSE

B17 Ultimate Coal Analysis

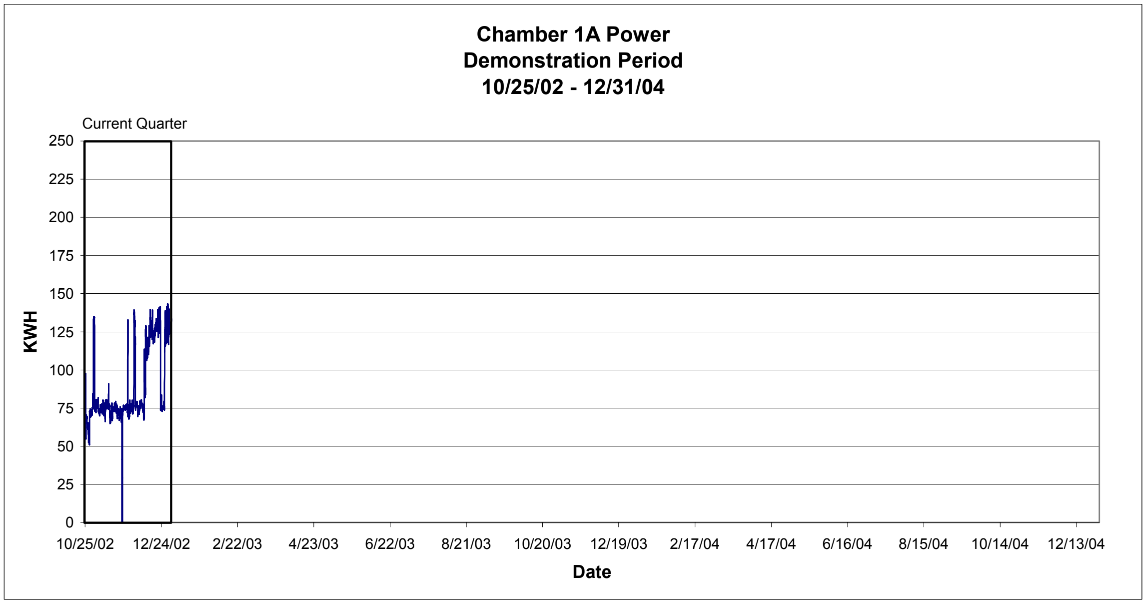
ULTIMATE ANALYSIS
AS RECEIVED

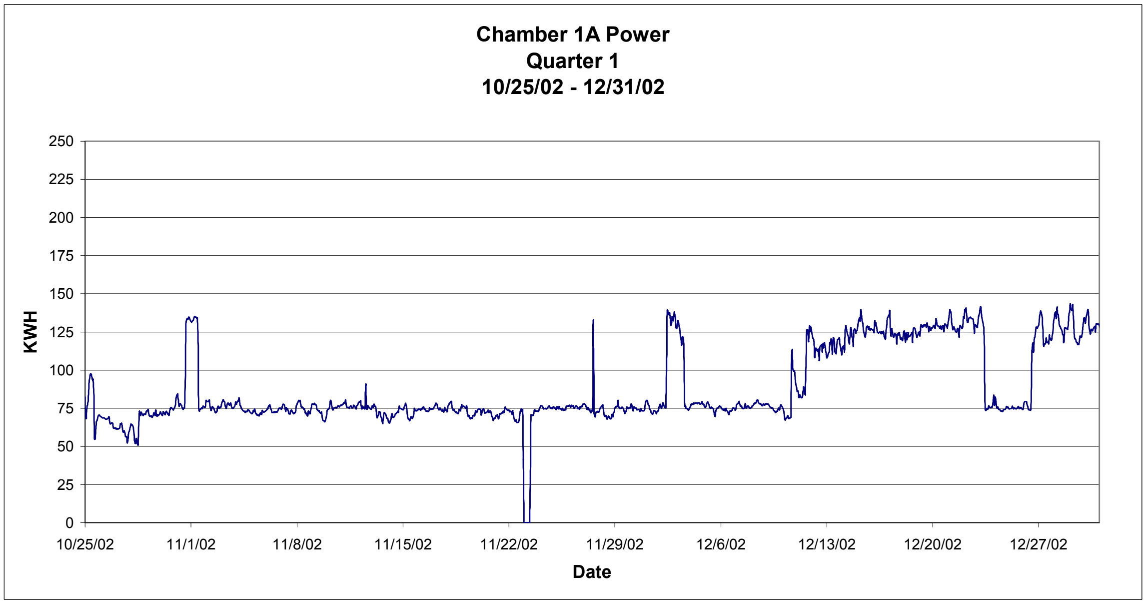
Sample Date	Moisture %	Ash %	Carbon %	Nitrogen %	Sulfur %	Hydrogen %	Oxygen %	HHV btu/lb	NaO %	Mercury ug/g Dry
06-Jan-02	29.59	5.16	49.23	0.70	0.39	3.95	10.98	8469	1.50	
13-Jan-02	29.10	5.03	49.68	0.70	0.36	3.54	11.59	8656	1.00	0.169
20-Jan-02	30.11	5.00	49.25	0.70	0.37	3.77	10.80	8492	1.40	
28-Jan-02	29.61	4.59	49.60	0.71	0.39	3.74	11.36	8568	1.80	
03-Feb-02	29.80	4.98	48.68	0.66	0.40	3.80	11.68	8570	1.80	
10-Feb-02	28.86	4.81	49.03	0.64	0.39	3.76	12.51	8656	1.40	0.096
17-Feb-02	29.44	4.57	49.11	0.65	0.35	3.57	12.31	8690	1.70	
24-Feb-02	30.24	4.94	48.63	0.71	0.36	3.70	11.42	8172	1.60	
03-Mar-02	30.08	5.00	48.83	0.65	0.35	3.76	11.33	8399	1.50	
10-Mar-02	29.56	4.66	49.69	0.65	0.32	3.75	11.37	8559	1.50	0.058
17-Mar-02	30.39	4.68	48.93	0.65	0.40	3.96	10.99	8440	1.50	
24-Mar-02	30.22	5.00	48.86	0.65	0.44	5.09	9.74	8357	1.60	
31-Mar-02	29.69	5.49	48.97	0.66	0.37	3.64	11.18	8410	1.20	
07-Apr-02	29.39	4.61	49.58	0.64	0.35	3.52	11.91	8660	1.70	
14-Apr-02	29.44	4.72	48.80	0.74	0.42	3.16	12.72	8528	1.50	0.113
21-Apr-02	29.80	4.20	49.70	0.64	0.35	3.47	11.84	8582	1.40	
28-Apr-02	27.53	4.58	50.37	0.69	0.32	3.77	12.74	8653	1.40	
05-May-02	29.69	4.45	48.92	0.65	0.30	3.63	12.36	8550	1.40	
12-May-02	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	
19-May-02	29.07	4.85	49.39	0.65	0.38	3.60	12.06	8627	1.60	0.087
26-May-02	29.88	4.27	49.32	0.67	0.30	3.69	11.87	8483	1.90	
02-Jun-02	28.53	4.80	48.88	0.76	0.27	3.97	12.79	8557	1.60	
09-Jun-02	30.24	4.69	48.26	0.63	0.37	3.56	12.25	8381	1.30	0.07
16-Jun-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	
23-Jun-02	26.23	5.18	51.01	0.67	0.36	3.81	12.74	8818	1.00	
30-Jun-02	29.28	4.67	48.65	0.70	0.32	3.74	12.64	8500	1.50	
07-Jul-02	29.29	4.89	49.15	0.72	0.24	3.74	11.97	8509	1.00	
14-Jul-02	29.60	4.79	48.44	0.69	0.28	3.95	12.25	8528	1.40	0.073
21-Jul-02	28.39	4.43	49.24	0.64	0.31	4.12	12.87	8636	1.20	
28-Jul-02	28.32	4.17	49.80	0.66	0.25	4.08	12.72	8629	1.50	
04-Aug-02	29.35	4.23	49.41	0.64	0.30	3.96	12.11	8644	1.40	
11-Aug-02	29.57	4.92	48.53	0.65	0.27	3.36	12.70	8487	1.00	0.078
18-Aug-02	30.00	4.67	48.33	0.67	0.37	3.66	12.30	8440	1.30	
25-Aug-02	30.01	5.08	47.26	0.66	0.39	3.53	13.07	8291	1.50	
01-Sep-02	29.07	4.17	49.39	0.63	0.31	3.65	12.78	8692	1.90	
08-Sep-02	29.16	4.62	48.90	0.69	0.34	3.58	12.71	8579	2.00	0.099
15-Sep-02	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	
22-Sep-02	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	
29-Sep-02	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	
06-Oct-02	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	
13-Oct-02	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	
20-Oct-02	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	
27-Oct-02	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	
03-Nov-02	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	
10-Nov-02	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	Outage	
17-Nov-02	29.90	4.16	49.30	0.65	0.30	3.41	12.28	8568	1.50	
24-Nov-02	30.15	5.06	48.38	0.66	0.28	3.22	12.25	8375	1.20	0.074
08-Dec-02	28.99	4.40	49.89	0.62	0.24	3.67	12.19	8649	1.30	
15-Dec-02	29.35	4.32	49.52	0.66	0.27	3.57	12.31	8699	1.40	0.249
22-Dec-02	29.21	4.23	49.77	0.63	0.26	3.44	12.46	8653	1.60	
29-Dec-02	29.61	5.21	48.48	0.63	0.40	3.50	12.17	8410	1.40	
Average	29.39	4.71	49.13	0.67	0.34	3.71	12.06	8539.15	1.46	0.11

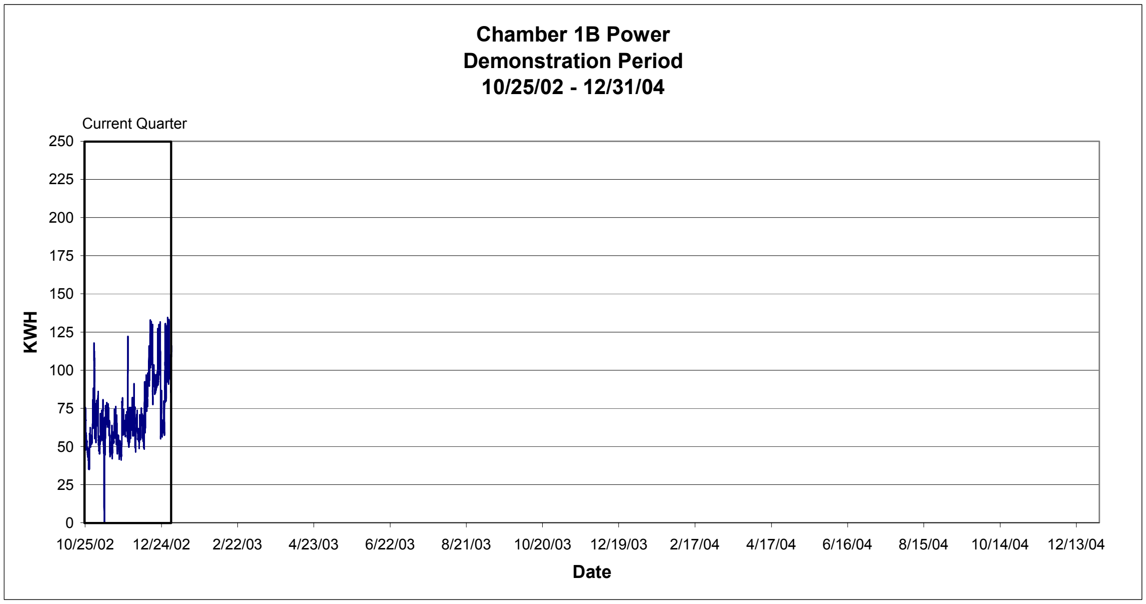
B18 Photographs

None applicable this quarter

B19 ESP Power by Chamber



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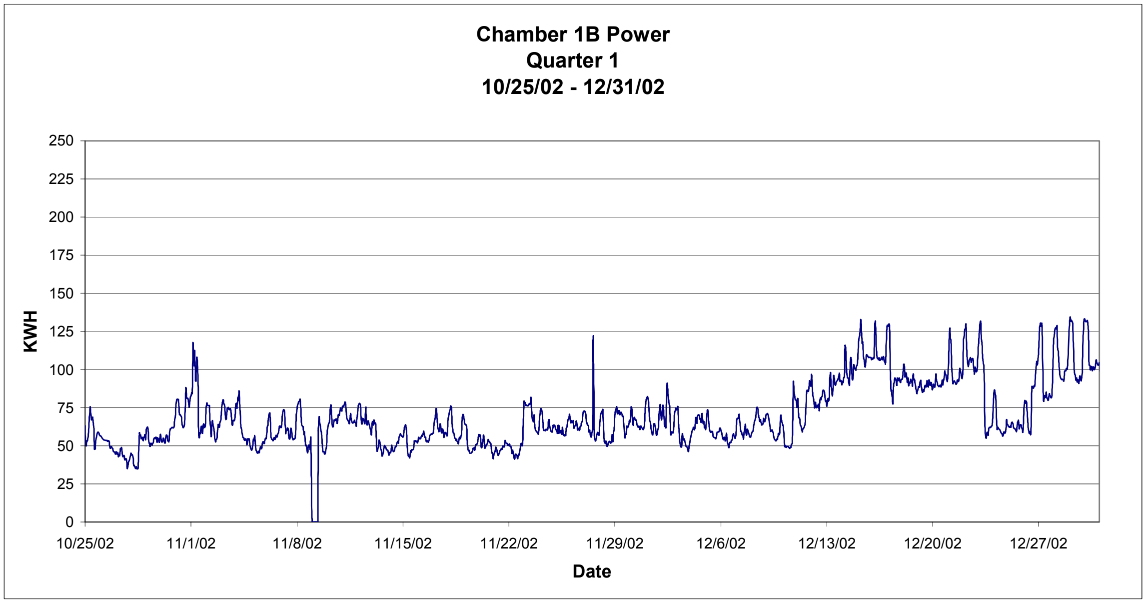
10/25/02 - 12/31/04
Current Quarter
250
225
200
175
150
125
100
75
50
25
0
KWH
10/25/02
12/24/02
2/22/03
4/23/03
6/22/03
8/21/03
10/20/03
12/19/03
2/17/04
4/17/04
6/16/04
8/15/04
10/14/04
12/13/04
Date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225
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11/1/02
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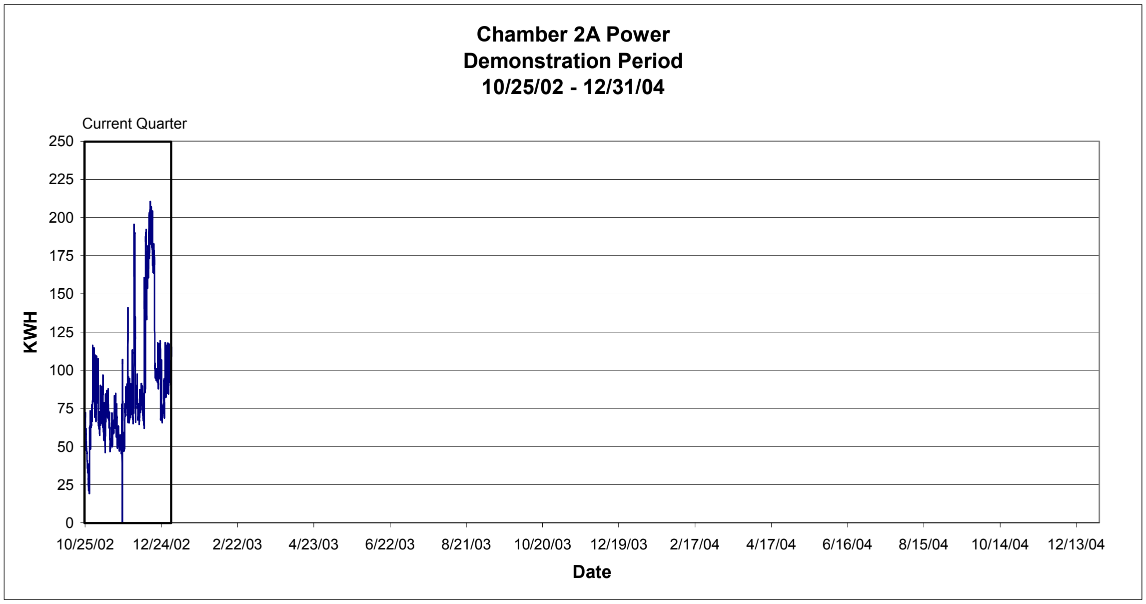
12/13/02
12/20/02
12/27/02
Date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12/24/02
2/22/03
4/23/03
6/22/03
8/21/03
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4/17/04
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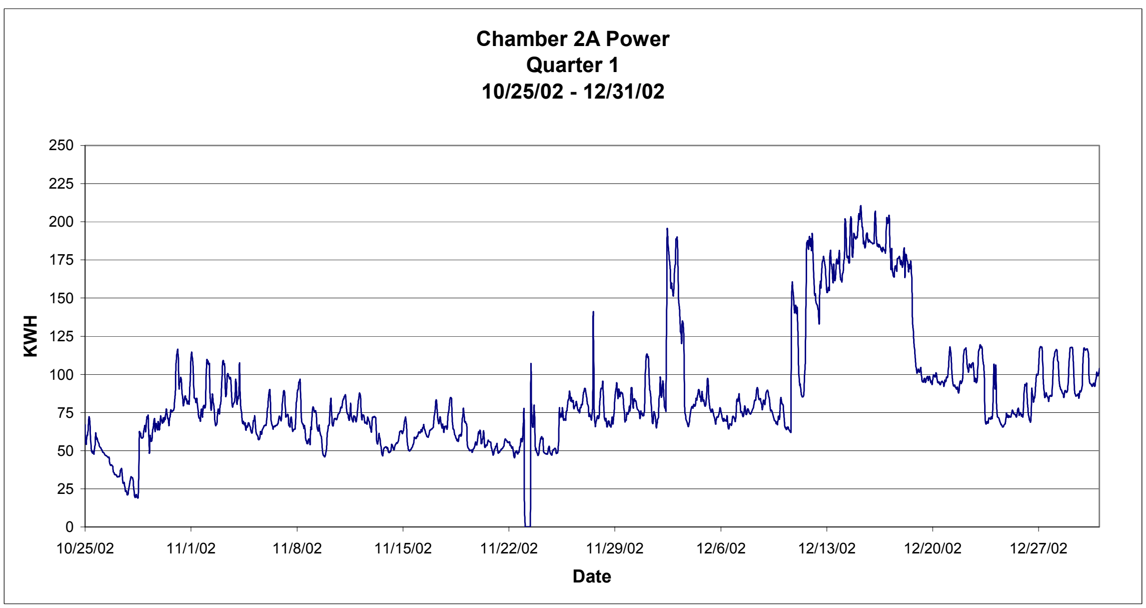
10/14/04
12/13/04
Date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10/25/02 - 12/31/02
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125
100
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11/1/02
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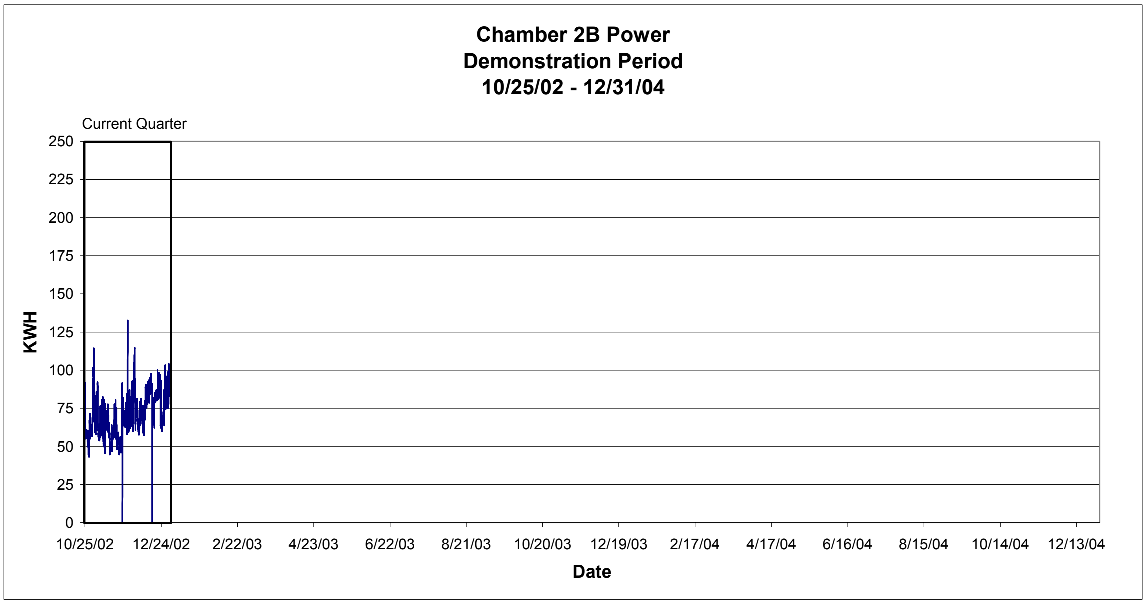
12/20/02
12/27/02
Date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Demonstration Period
10/25/02 - 12/31/04
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25
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10/25/02
12/24/02
2/22/03
4/23/03
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8/21/03
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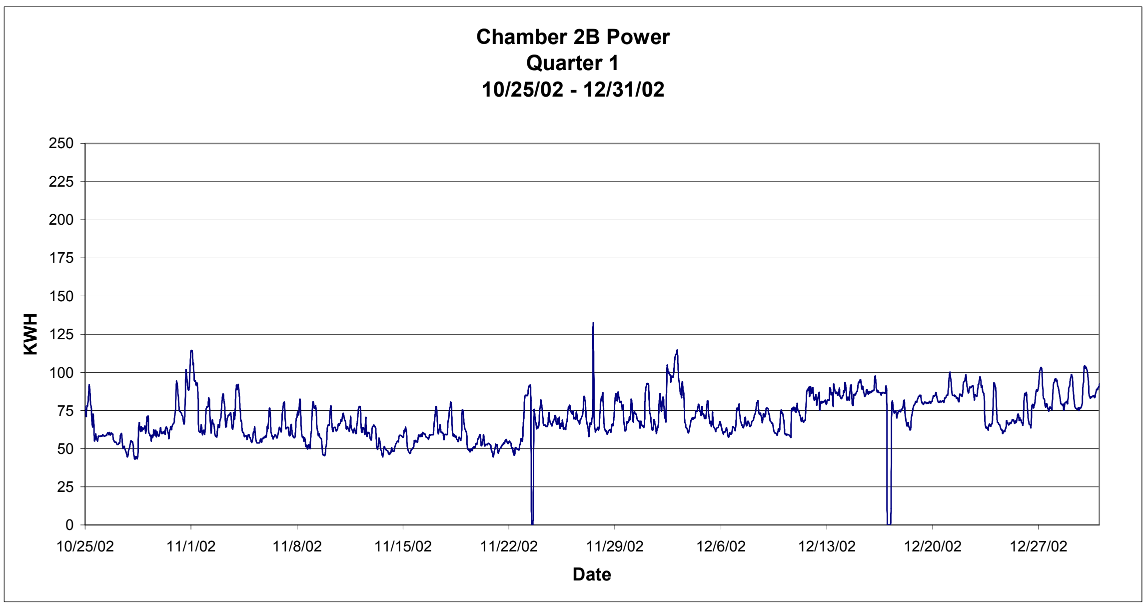
10/14/04
12/13/04
Date


Chamber 2B Power
Quarter 1
10/25/02 - 12/31/02
KWH
250
225
200
175
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125
100
75
50
25
0
10/25/02
11/1/02
11/8/02
11/15/02
11/22/02
11/29/02
12/6/02
12/13/02
12/20/02
12/27/02
Date

B20 ESP Tabular Data

Transformer/Rectifier Performance Readings

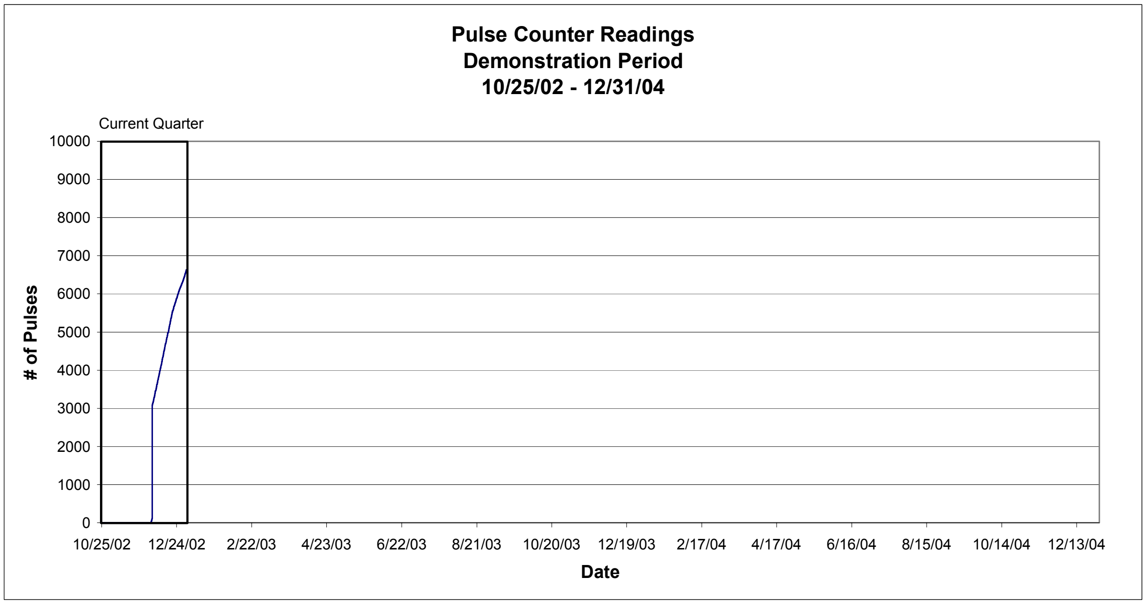
28-Oct-02	Limits: mA = 700, kV = 45, spm = 12											
Chamber	Field 1			Field 2			Field 3			Field 4		
	mA	kV	spm	mA	kV	spm	mA	kV	spm	mA	kV	spm
1A	--	--	--	320	45.6	11	705	48.4	2	705	50.3	0
1B	--	--	--	254	46.9	11	711	45	11	711	45.6	2
2A	--	--	--	432	53.6	13	320	48.4	12	569	47.6	12
2B	--	--	--	361	47.2	12	645	42.2	11	592	44.8	10

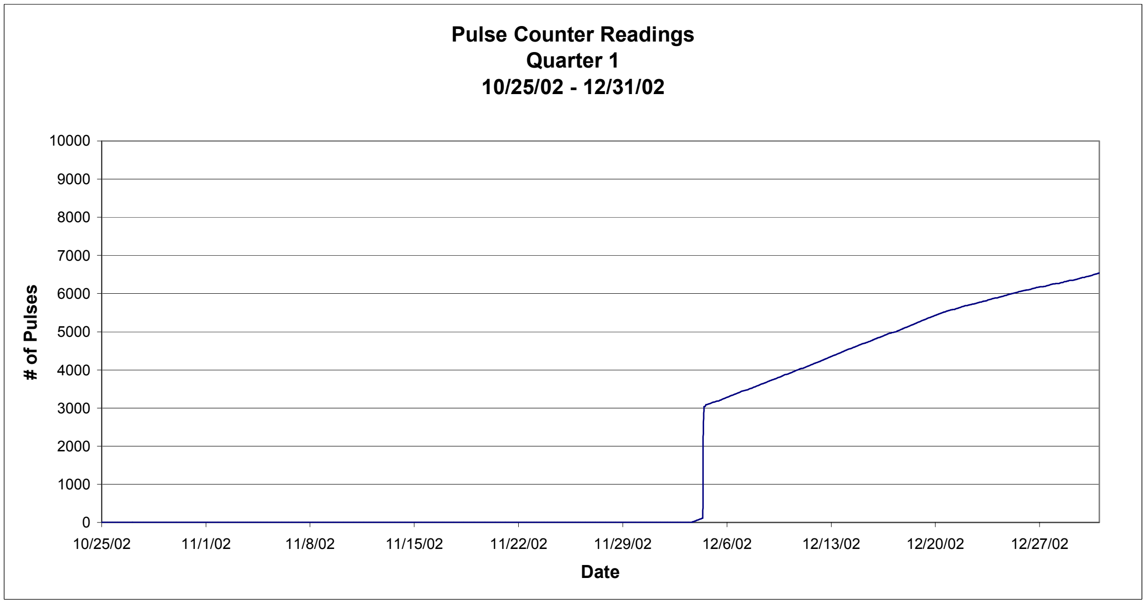
29-Oct-02	Limits: mA = 700, kV = 45, spm = 12											
Chamber	Field 1			Field 2			Field 3			Field 4		
	mA	kV	spm	mA	kV	spm	mA	kV	spm	mA	kV	spm
1A	--	--	--	296	45.4	12	705	47.2	0	705	50.5	0
1B	--	--	--	284	48.7	13	569	45.6	12	684	47	13
2A	--	--	--	409	54	11	284	50.2	12	699	50.7	11
2B	--	--	--	391	49.2	11	664	43.8	12	711	46.2	10

30-Oct-02	Limits: mA = 700, kV = 45, spm = 12											
Chamber	Field 1			Field 2			Field 3			Field 4		
	mA	kV	spm	mA	kV	spm	mA	kV	spm	mA	kV	spm
1A	--	--	--	320	40.4	12	711	47.9	1	705	50.8	0
1B	--	--	--	260	49.2	11	652	47.3	11	703	47.3	10
2A	--	--	--	503	53.8	12	343	50.8	12	705	52	3
2B	--	--	--	260	48	14	592	45.7	11	675	48.6	12

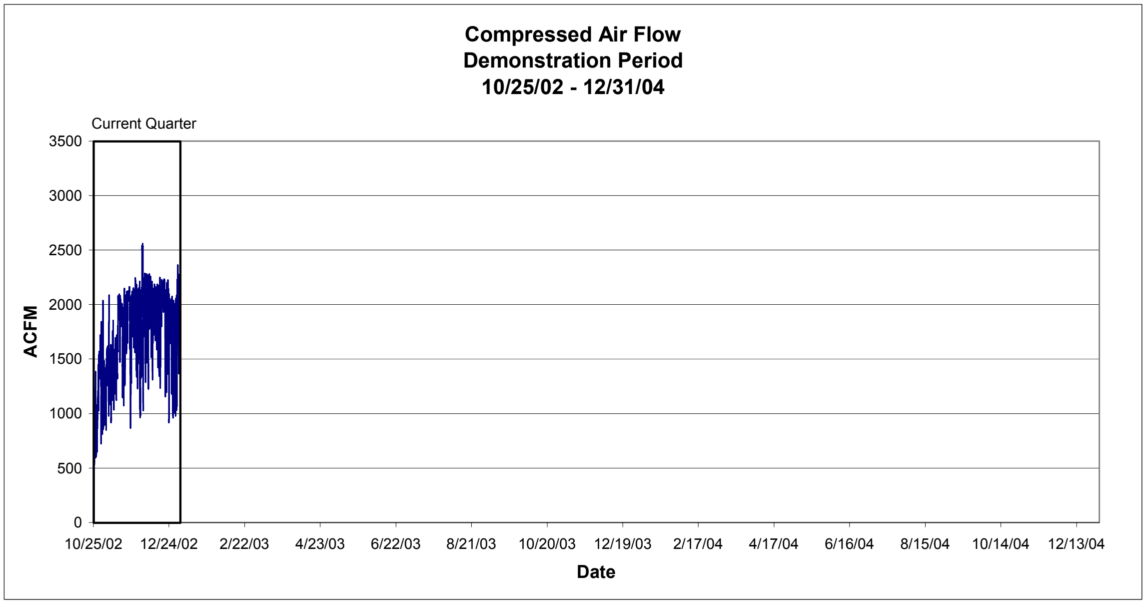
22-Nov-02	Limits: mA = 700, kV = 65, spm = 50 for F2 and 12 for F3 and F4											
Chamber	Field 1			Field 2			Field 3			Field 4		
	mA	kV	spm	mA	kV	spm	mA	kV	spm	mA	kV	spm
1A	--	--	--	332	46.7	49	664	48.1	11	705	54.1	3
1B	--	--	--	278	51.3	50	557	49.1	12	213	43.2	11
2A	--	--	--	361	51.8	50	284	44.7	12	592	50.9	12
2B	--	--	--	367	50.9	49	391	49.5	12	616	46.6	12

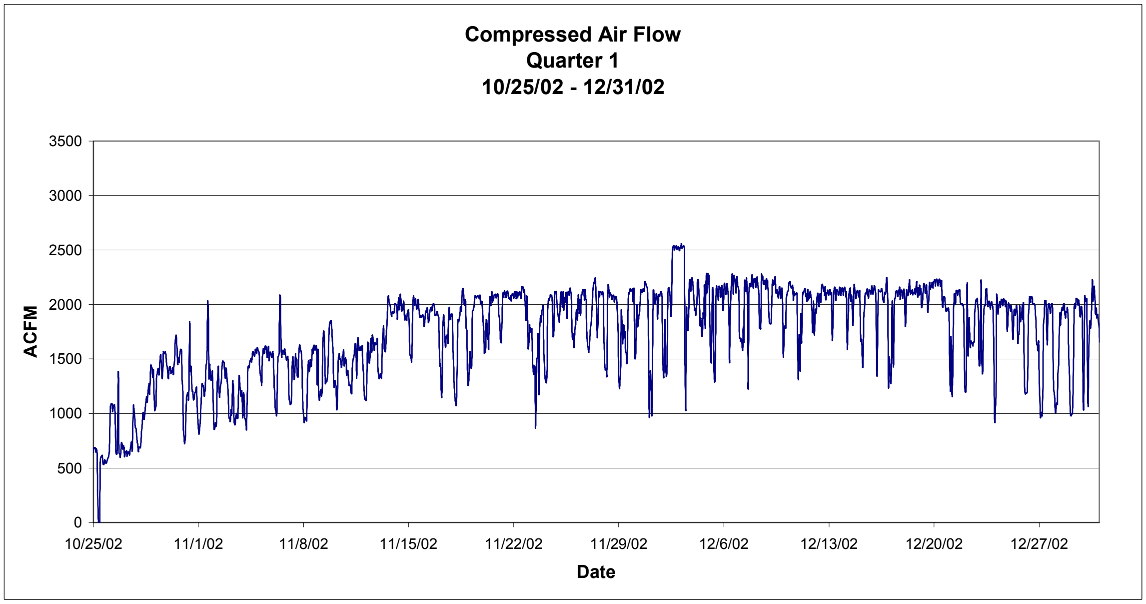
B21 Pulse Counter Readings



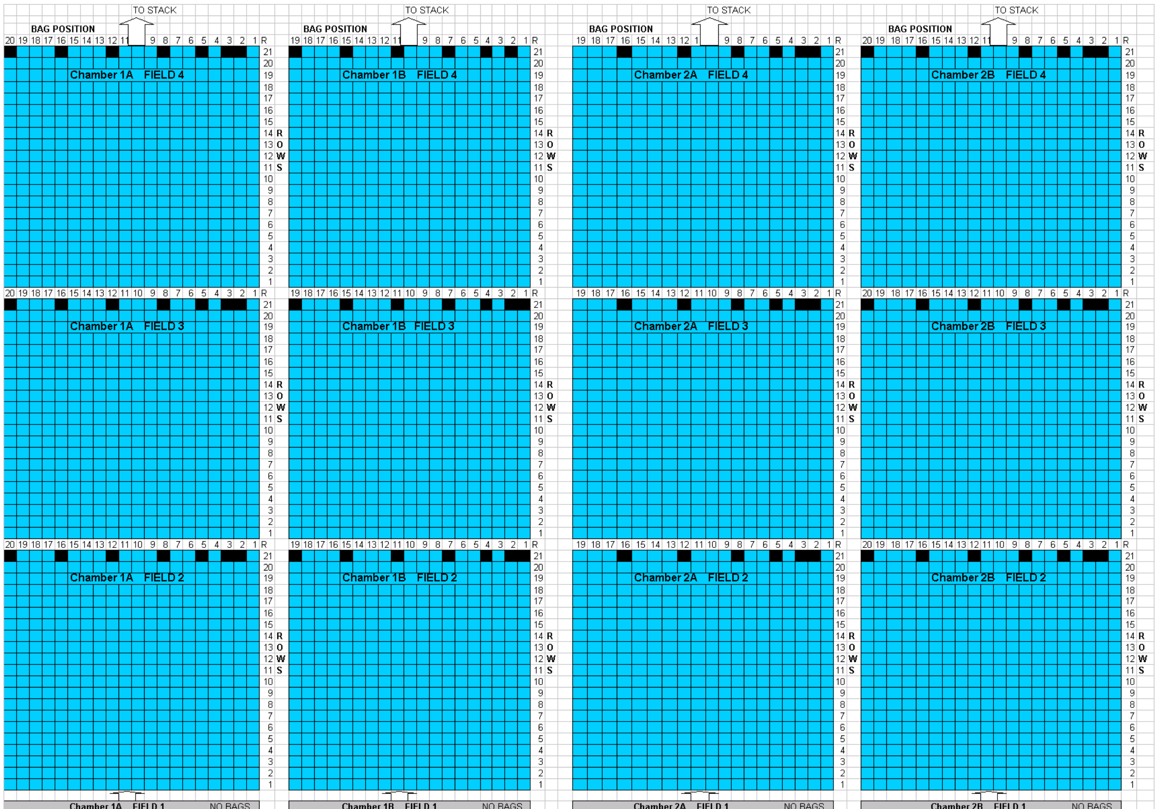


B22 Compressed Air Flow





B23 Bag Layout Diagram



No Filter Bag

Conductive Gore-Tex Membrane/Conductive Gore-Tex Felt (Installed 10/02)

B24 EERC Stack Test (17 pages total)

Support in Demonstrating a Full-Scale Retrofit of the Advanced Hybrid™ Technology – TEST SERIES I

Test Series I Report

(For the period June 1, 2002 – January 22, 2003)

Prepared for:

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January 2003

EERC DISCLAIMER

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SAMPLING SUPPORT TO DEMONSTRATE A FULL-SCALE RETROFIT OF THE ADVANCED HYBRID™ TECHNOLOGY – TEST SERIES I

INTRODUCTION

A new concept in particulate control, called the Advanced Hybrid™ Filter, was installed at the Big Stone Power Plant operated by Otter Tail Power Company. The Advanced Hybrid™ concept combines fabric filtration and electrostatic precipitation in the same housing, providing major synergism between the two methods, both in the particulate collection step and in the transfer of dust to the hopper. The Advanced Hybrid™ Filter is designed to provide ultrahigh collection efficiency for even fine particulate matter at air-to-cloth ratios significantly higher than those utilized for traditional fabric filters, 10–12 ft/min compared to 3.5–4 ft/min for a pulse-jet baghouse. This report presents the results of the first series of flue gas sampling designed to demonstrate the fine particulate collection efficiency of the Advanced Hybrid™ Filter. In addition to total particulate measurements, trace elements including mercury, were also measured.

APPROACH

The original proposal required testing three times during the first 2 years of operation. The results presented in this report were those obtained after about 600 hours of operation. The Advanced Hybrid™ Filter began operating on October 25, 2002, and sampling occurred during the week of November 18, 2002. Table 1 shows the test matrix for the sampling conducted during this period.

Table 1. Sampling Test Matrix for Big Stone Power Plant – Test Series I

Activity	Sampling Location	Nov. 18 AM	Nov. 18 PM	Nov. 19 AM	Nov. 19 PM	Nov. 20 AM	Nov. 20 PM	Nov. 21 AM	Nov. 21 PM	Nov. 22 AM	Nov. 22 PM
Set-Up and Takedown		Setup								Takedown	
APS/SMPS[1]	Stack			APS/SMPS							
EPA Method 29[2]	Advanced Hybrid™ Inlet			X		X	X				
EPA Method 29	Stack			X		X	X				
EPA Method 17	Stack		X			X		X			
Multicyclones	Advanced Hybrid™ Inlet				X			X	X		
Impactor	Stack					X					
Coal Samples and Hopper Ash				X		X		X		X	

[1] Aerodynamic particle sizer (APS)/scanning mobility particle sizer (SMPS).
[2] U.S. Environmental Protection Agency.

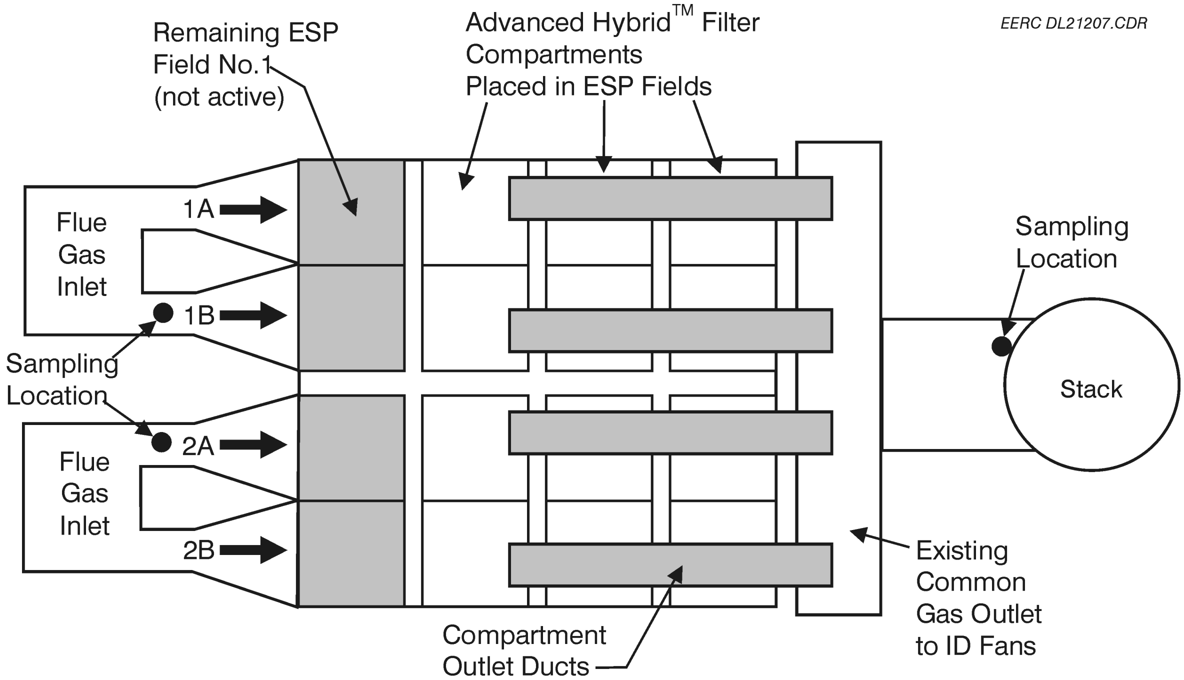

Figure 1. Schematic of the Big Stone Power Plant showing Advanced Hybrid™ System and sampling locations.

The Advanced Hybrid™ system has four chambers (1A, 1B, 2A, and 2B) with a separate duct going to each chamber. These ducts recombine at the outlet of the Advanced Hybrid™ Filter and exit a single stack. Figure 1 is a schematic of the system showing the flue gas sampling points. As can be seen in Figure 1, the Advanced Hybrid™ inlet sampling was done at two different ducts, 1B and 2A.
The reason for this is that the first duct did not have a port large enough to use the multicyclone. Therefore, sampling location was changed from the second duct to the third duct. The sampling in the stack was done at a 288-ft level. There were four ports located in the stack. One port was used to do EPA Method 29 samples, and a different port was used to collect the EPA Method 17 samples. No traversing was done for these tests.

The fuel burned at the Big Stone Power Plant varies to some degree. The coal is a Powder River Basin (PRB) subbituminous coal from the Belle Ayr mine. However, periodically, the Big Stone Power Plant blends 10% or less of other combustible materials, including tire-derived fuel (TDF) and a waste seed biomass such as corn. Table 2 shows the fuel that was burned during the four days of testing.

The coal samples provided the Energy & Environmental Research Center (EERC) by plant personnel for the 4 days of testing were as follows (these samples were not taken directly at the mill, so they are different than those actually burned at the plant on any given day).

Table 2. Fuel Burned at the Big Stone Power Plant During Testing, by weight

Day	Coal, %	TDF, %	Waste Seed (Corn), %
Nov. 19	96.5	0.4	3.1
Nov. 20	100	0	0
Nov. 21	100	0	0
Nov. 22	95.0	2.2	2.8

11/18/2002	PRB–waste corn seed
11/18/2002	TDF
11/19/2002	PRB
11/20/2002	PRB
11/21/2002	PRB
11/22/2002	PRB

The TDF sample was taken prior to mixing with the coal, but the waste corn seed was blended with the coal prior to the sample being taken. The sampling protocols used for the Test Series I sampling effort are presented in Table 3. The trace elements analyzed were as follows:

Antimony
Arsenic
Beryllium
Cadmium
Chromium
Lead
Nickel
Mercury

At the Advanced Hybrid™ inlet sampling location, the EPA Method 29 and multicyclones were operated for about 2 hours. However, because of the very low emissions at the stack, the EPA Method 17 and impactor trains were operated for 12 hours to ensure enough dust was captured to accurately measure weight. To improve the detection of the trace elements at the stack, EPA Method 17 filters were analyzed, rather than the stack EPA Method 29 filters. To sample the required amount of flue gas isokineticlly, EPA Method 29 can only be operated 2–3 hours compared to 12 hours for EPA Method 17.

RESULTS AND DISCUSSION

Coal Analysis

One coal–waste corn blend sample and three PRB coal samples were analyzed for this project for trace elements and chlorides. These results are shown in Table 4. With the exception of nickel, the addition of waste corn seed to the coal reduces all the trace elements.

Table 3. Sampling Protocols Used for Test Series I

Sample Method	Analysis
EPA Method 29	Trace elements and total dust loading at the Advanced Hybrid™ inlet (fly ash and flue gas)
EPA Method 17	Trace elements and total dust loading at the stack (fly ash)
Multicyclones	Particle-size distribution at the Advanced Hybrid™ inlet
Impactor	Particle-size distribution at the stack
APS/SMPS	Particle-size distribution at the stack (0.03–15 µm)
Sample	
Hopper Ash[1]	Trace elements, XRF[2] analyses for major elements, and loss on ignition (LOI)
Coal[3]	Trace elements, ultimate/proximate, heating value and chlorine

[1] Analyses were done on three hopper ash samples.
[2] X-ray fluorescence.
[3] Analyses were done on four coal samples, 3 PRB only and 1 PRB plus waste corn seed.

Table 4. Analyses of Trace Elements in Fuel Fired at Big Stone Power Plant

Date	11/19/02	11/21/02	11/22/02	11/22/02
Trace Element	PRB Coal, µg/g	PRB Coal, µg/g	PRB Coal, µg/g	PRB and waste corn seed, µg/g
Antimony	<0.1	<0.1	<0.1	<0.1
Arsenic	0.56	1.1	0.60	0.49
Beryllium	0.21	0.27	0.26	0.15
Cadmium	0.064	0.10	0.060	<0.04
Chromium	3.5	4.3	4.3	2.84
Chloride	8.9	22.0	9.1	200
Lead	3.5	3.3	2.9	2.0
Mercury	0.087	0.0414	0.0586	0.0754
Nickel	5.3	5.8	4.2	14.8

Ultimate and proximate analyses for one PRB coal and the PRB-waste corn seed blend are shown in Table 5.

Total Dust Loadings and Particulate Collection Efficiency

The total particulate collection efficiency is shown in Table 6. As can be seen, the average collection efficiency is >99.995%. Based on the original proposal, the design specifications for the Advanced Hybrid™ Filter were <0.002 grains/scf and >99.99% collection efficiency. The results presented in Table 6 show that the Advanced Hybrid™ technology easily met these criteria.

Particle-Size Distributions

Near-real-time measurements were made for particles raging from 0.5 to 15 µm with the APS. For the APS, rather than looking at emissions of several particle sizes, fine particle emissions are combined by calculating a value for respirable mass. The American Council of Governmental and

Table 5. Chemical Analysis of Coal, as received

Date	11/19/2002	11/22/2002
Description	100% PRB	PRB and waste corn seed
Proximate Analysis		
Moisture, %	29.50	21.60
Volatile Matter, %	33.24	37.97
Fixed Carbon, %	32.95	27.18
Ash, %	4.31	13.26
Ultimate Analysis		
Hydrogen, %*	6.66	6.15
Carbon, %	48.60	53.33
Nitrogen, %	0.86	0.92
Sulfur, %	0.31	0.35
Oxygen, % (by diff.)	39.26	26.00
Heating Value, Btu/lb	8520	9658
Fd, dscf/10^6 Btu	9488	9562

*Includes hydrogen as water.

Table 6. Advanced Hybrid™ Particulate Collection Efficiency

Date	Sample Method	Advanced Hybrid™ Inlet Dust Loading, grains/scf	Advanced Hybrid™ Inlet[1] Dust Loading, lb/10^6 Btu	Stack Dust Loading, grains/scf	Stack[1] Dust Loading, lb/10^6 Btu	Particulate Collection Efficiency, %
11/18/2002	EPA Method 17			0.00002	0.00003	99.998
11/19/2002	EPA Method 29	1.02092	1.38378			
	Multicyclones	0.64099	0.86882			
11/20/2002	EPA Method 17			0.00006	0.00008	99.994
	EPA Method 29	0.85856	1.16372			
	EPA Method 29	0.92151	1.24904			
11/21/2002	EPA Method 17			0.00003	0.00004	99.997
	Multicyclones	0.66113	0.89611			
	Multicyclones	0.70044	0.94940			

[1] Values were calculated based on the Fd factors shown in Table 3 for 100% PRB.

Industrial Hygienists (ACGIH) definition of respirable mass is presented in Table 7. The ACGIH definition is extrapolated and interpolated to calculate the percentage at the midpoint of each channel for that particle size, as determined by the APS. The respirable mass from all the channels is added to obtain the total respirable mass. This provides a convenient and effective method of showing APS results for fine particle emissions. The results for the APS sampling are presented in Figures 2–4. The results show, with the exception of one spike, that the Advanced Hybrid™ respirable mass emissions are at or below those measured in the ambient air.

Table 7. ACGIH Respirable Mass Definition

Aerodynamic Diameter, µm	Respirable Mass Fraction, %
<2.0	100
2–2.5	90
2.5–3.5	75
3.5–5.0	50
5.0–10.0	25
>10	0

Particle-size distribution was measured at the Advanced Hybrid™ inlet using a 5-stage multicyclone and at the stack using an impactor. The Advanced Hybrid™ inlet multicyclone results are presented in Figure 5. As shown in Figure 5, the results for the three multicyclone samples at the inlet are similar and give a mass mean diameter of about 10 µm. The impactor results at the stack are shown in Figure 6. The results of the impactor are somewhat suspect because the total particulate loading, even after 12 hours of sampling, was so low that is was difficult to measure accurately. However, as shown in Figure 5, the mass loading measured at the stack was substantially finer. The D_{50} was <0.2 µm.

Flue Gas Analyses

The trace element analyses of the flue gas at the Advanced Hybrid™ inlet and the stack is shown in Tables 8 and 9. As would be expected based on the vapor pressure for the measured trace elements (with the exception of mercury), the vast majority of each of the trace elements is bound with the particulate matter. It should be noted that the vapor-phase lead values are somewhat suspect, as the field blanks indicated concentrations higher then would be expected. The field blank results are shown in Table 10. The field blank data shown in Table 8 are the total amount of each trace element in the impinger solutions of EPA Method 29. Table 9 represents the blanks for the gas-phase concentrations.

Comparing the Advanced Hybrid™ inlet and stack trace element analysis (Table 11) shows the Advanced Hybrid™ was extremely efficient, removing all the measured trace elements with the exception of the vapor-phase mercury. In an attempt to get a measurable quantity of trace elements, the filters from the EPA Method 17 samples were analyzed. The EPA Method 17 sample trains were operated for 12 hours, compared to only two for the EPA Method 29 trains. For all three samples taken at the stack, the trace elements, again with the exception of mercury, was at or below detection limits.

Mass Balances

In addition to the EPA Method 17 samples, fly ash samples were also taken from the hopper of the pilot-scale Advanced Hybrid™ that was running at the time. These samples were analyzed for major and trace elements as shown in Tables 12 and 13. The trace element analyses results from the ash samples compared quite well with those obtained from EPA Method 17 samples from the full-

Table 8. Analyses of Trace Elements in Flue Gas at the Advanced Hybrid™ Inlet[1,2]

Day	11/19/02			11/20/02			11/20/02		
Time	10:50			09:30			13:37		
Fuel	PRB, TDF, and Corn Seed			100% PRB			100% PRB		
Trace Element	Part.-bound, µg/Nm^3	Vapor-Phase, µg/Nm^3	Total, µg/Nm^3	Part.-bound, µg/Nm^3	Vapor-Phase, µg/Nm^3	Total, µg/Nm^3	Part.-bound, µg/Nm^3	Vapor-Phase, µg/Nm^3	Total, µg/Nm^3
Antimony	26.7	0.5	26.7	17.6	0.7	17.6	15.0	0.6	15.0
Arsenic	53.5	2.0	53.5	48.0	2.6	48.0	51.5	2.5	51.5
Beryllium	2.9	0.5	2.9	6.4	0.7	6.4	2.7	0.6	2.7
Cadmium	7.5	0.2	7.5	5.3	0.2	5.3	4.9	0.2	4.9
Chromium	49.4	1.4	50.8	49.4	0.6	50.0	66.0	1.6	67.6
Lead	251.5	4.2	255.7	215.9	2.1	218.0	210.9	3.0	216.9
Mercury	3.2	4.5	7.7	2.3	7.4	9.7	6.8	7.7	14.5
Nickel	228.5	3.2	231.7	191.7	4.3	196.0	170.2	3.7	173.9

[1] Shaded results are below detection limits. The shown values are the detection limits. Those results that are below detection limits are not added to calculate the total concentrations.

[2] Particulate-bound trace elements were based on the filters of the EPA Method 17 samples.

Table 9. Analyses of Trace Elements in Flue Gas at the Stack[1]

Day	11/19/02			11/20/02			11/20/02		
Time	11:08			09:25			13:25		
Fuel	PRB, TDF, and Corn Seed			100% PRB			100% PRB		
Trace Element	Part.-bound, µg/Nm^3	Vapor-Phase, µg/Nm^3	Total, µg/Nm^3	Part.-bound, µg/Nm^3	Vapor-Phase, µg/Nm^3	Total, µg/Nm^3	Part.-bound, µg/Nm^3	Vapor-Phase, µg/Nm^3	Total, µg/Nm^3
Antimony	<2.1	<0.5	ND[2]	<2.2	0.5	ND	<2.2	0.5	ND
Arsenic	<1.4	<1.8	ND	<1.5	1.9	ND	<1.5	<1.9	ND
Beryllium	<0.7	<0.5	ND	<0.7	0.5	ND	<0.7	0.5	ND
Cadmium	<0.05	<0.1	ND	<0.05	0.1	ND	<0.05	0.1	ND
Chromium	<0.05	0.4	0.4	<0.05	0.5	0.5	<0.05	0.5	0.5
Lead	2.5	1.5	4.0	<1.5	1.4	1.5	<1.5	<1.0	ND
Mercury	<0.05	5.4	5.4	<0.05	6.1	6.1	<0.05	6.5	6.5
Nickel	<0.05	3.0	3.0	<0.05	1.7	1.7	<0.05	1.0	1.0

[1] Shaded results are below detection limits. The shown values are the detection limits. Those results that are below detection limits are not added to calculate the total concentrations.

[2] ND (not detected) is defined as those results where both forms of the trace element are below detection limits.

scale unit. Some of these trace elements such as beryllium and chromium are very refractory and a large percentage of the total amount measured in the coal is expected to be in the bottom slag which was not analyzed. This was the case as the percentage of beryllium and chromium found in the ash compared as a function of that predicted by the coals was, 13.1% and 6.3%, respectively. The one element that would be predicted to be almost all (>99%) vaporized is mercury. Based on the average coal concentration, F_d factor, and the heating value of the coal, the mercury in the flue gas is predicted to be 12.3 µg/Nm^3 on a dry basis, the actual measured concentration is 9.7 µg/Nm^3 or a balance of 78.8%. It is also interesting to note that the antimony concentration in the coal was below detection limits but was measured in the fly ash both for both the pilot-scale and full-scale units. Using the detection limit of 0.1 µg/g in the coal, the F_d factor, and the heating value of the coal the

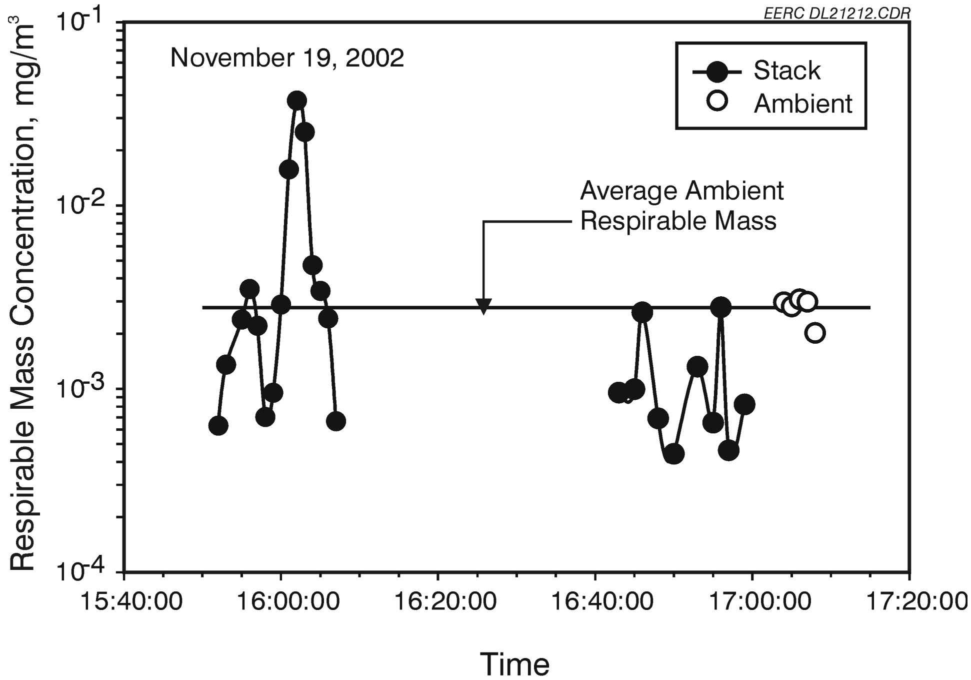

Figure 2. Respirable mass measurements at the stack of the Big Stone Power Plant for November 19, 2002.

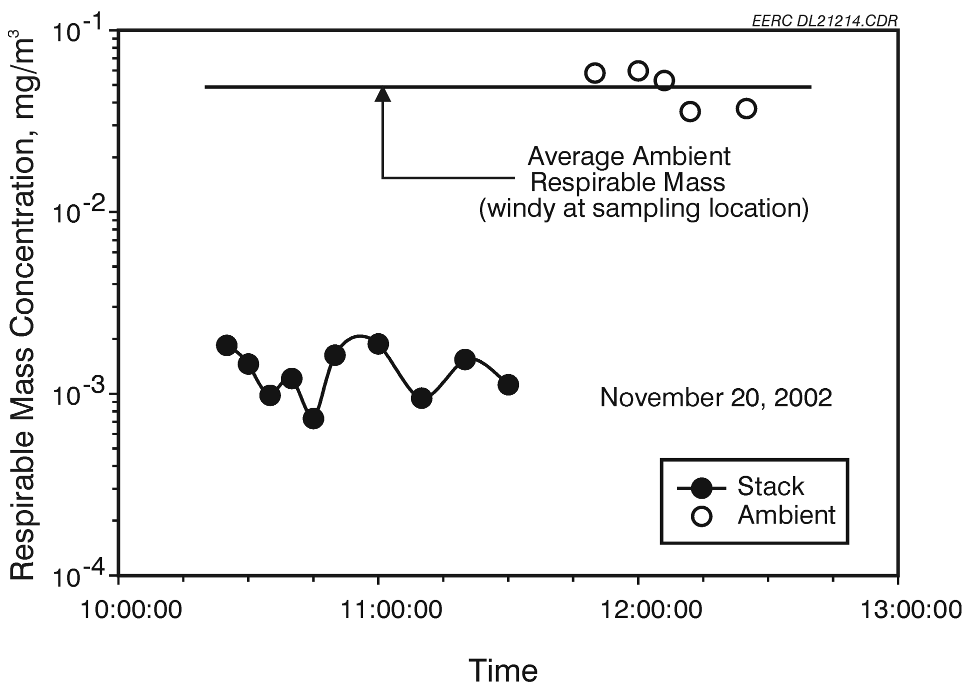

Figure 3. Respirable mass measurements at the stack of the Big Stone Power Plant for November 20, 2002.

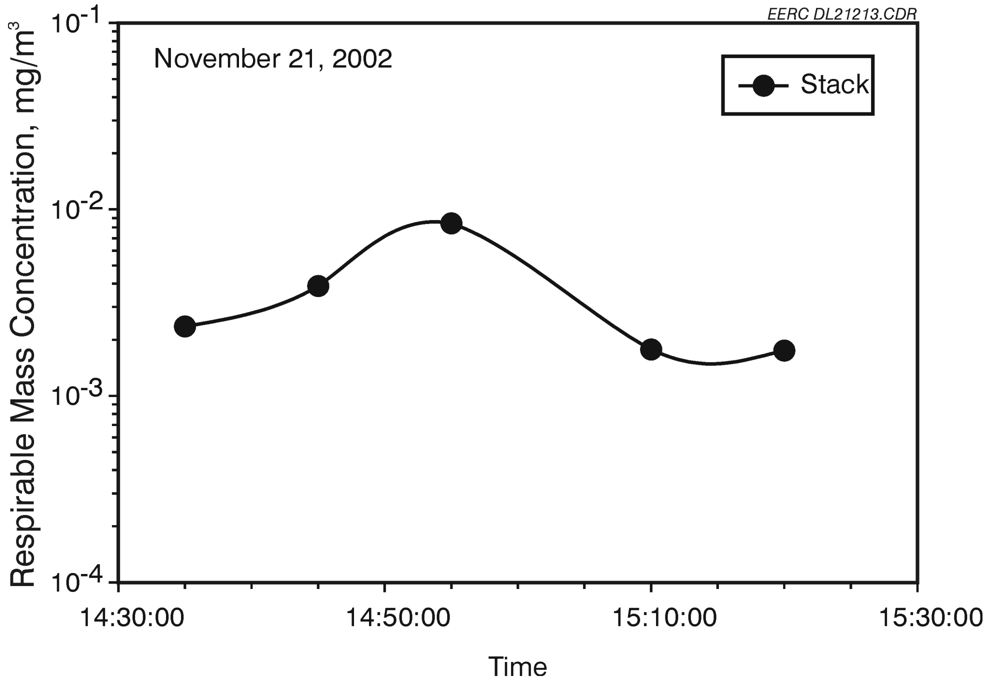

Figure 4. Respirable mass measurements at the stack of the Big Stone Power Plant for November 21, 2002.

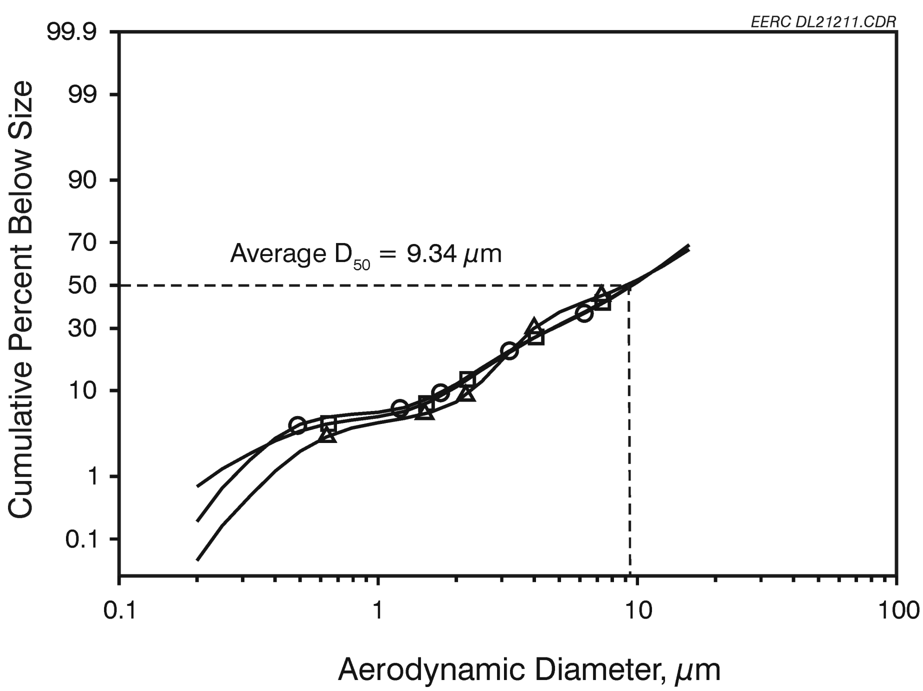

Figure 5. Particulate mass distribution at the Advanced Hybrid™ inlet based on mutlicyclone measurements.

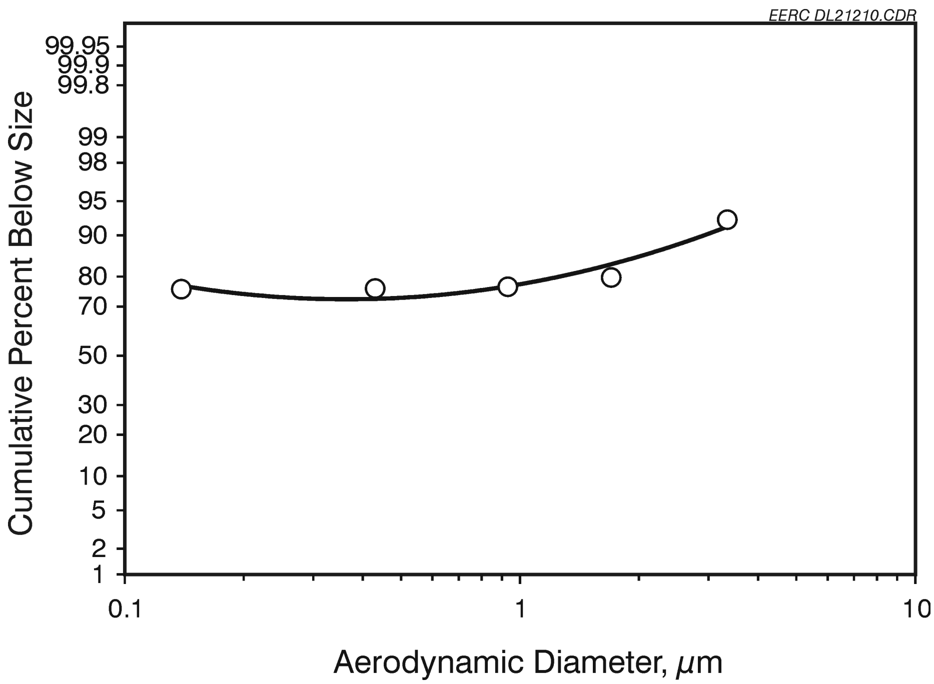

Figure 6. Particulate mass distribution at the stack based on an impactor measurement.

Table 10. Field Blank Results for EPA Method 29 Samples

	Day 1		Day 2	
Trace Element	μg	μg/Nm^3*	μg	μg/Nm^3*
Antimony	<0.05	<0.04	<0.05	<0.04
Arsenic	<2	<2	<2	<2
Beryllium	<0.5	<0.4	<0.5	<0.4
Cadmium	<0.15	<0.12	<0.15	<0.12
Chromium	0.23	0.19	0.20	0.16
Lead	3.5	3.1	3.1	2.5
Mercury	0.16	0.13	0.10	0.08
Nickel	0.85	0.69	<0.5	<0.4

*The gas concentration is calculated on the average volume of gas sampled for all the EPA Method 29 samples (1.227 Nm^3).

maximum concentration of antimony to the Advanced Hybrid™ is 19.7 μg/Nm^3. With the exception of one data point, all the measured concentrations in the ash for both the pilot- and full-scale units are just below the maximum value. Table 13 presents the major element analysis for one of the 100% PRB ashes. Also shown in Table 13 is the LOI for the three ashes.

Table 11. Comparison of the Concentration of Trace Elements at the Advanced Hybrid™ Inlet and Stack[1,2]

Day	11/19/02		11/20/02		11/20/02	
Time	11:08		09:25		13:25	
Fuel	PRB, TRF, and Corn Seed		100% PRB		100% PRB	
Trace Element	Advanced Hybrid™ Inlet, lb/10^{12} Btu	Stack, lb/10^{12} Btu	Advanced Hybrid™ Inlet, lb/10^{12} Btu	Stack, lb/10^{12} Btu	Advanced Hybrid™ Inlet, lb/10^{12} Btu	Stack, lb/10^{12} Btu
Antimony	15.8	ND[3]	10.4	ND	8.9	ND
Arsenic	31.7	ND	28.4	ND	30.5	ND
Beryllium	1.7	ND	3.8	ND	1.6	ND
Cadmium	4.4	ND	3.1	ND	2.9	ND
Chromium	30.1	0.2	29.6	0.3	40.0	0.3
Lead	151.3	2.4	129.0	0.9	128.4	ND
Mercury	4.6	3.2	5.7	3.6	8.6	3.8
Nickel	137.1	1.8	116.0	1.0	102.9	0.6

1 All values shown are calculated based on Tables 8 and 9 and the Fd factor shown in Table 5 for 100% PRB.
2 ND (not detected) is defined as those results where both the gas-phase and particulate bound forms of the trace elements are below detection limits.

Table 12. Trace Element Analyses of Pilot-Scale Advanced Hybrid™ Hopper Ash

Date	11/18/02		11/19/02		11/20/02	
Trace Element	µg/g	µg/Nm^3*	µg/g	µg/Nm^3*	µg/g	µg/Nm^3*
Antimony	6.7	14	6.3	14	6.9	15
Arsenic	19	41	20	43	21	45
Beryllium	1.9	4.1	2.2	4.72	1.9	4.08
Cadmium	2.1	4.5	2.1	4.5	2.1	4.5
Chromium	20	43	24	51	28	60
Lead	78.7	169	77.5	166	84.0	180
Mercury	0.655	1.41	0.564	1.21	0.551	1.18
Nickel	95	204	93	199	84	180

* The gas concentration is calculated on an average dust loading of 0.93664 gr/scf to the Advanced Hybrid™ hopper (from EPA Method 17 samples on full-scale unit).

CONCLUSIONS

From the data, the primary conclusion was that the Advanced Hybrid™ technology is extremely efficient in removing particulate matter. The particulate efficiency is substantially better than the designed basis of 99.990%. The average particulate collection efficiency was 99.997%. The outlet dust loading was almost an order of magnitude lower than the proposed limit of 0.002 grain/scf. As would be expected from a concept that provides ultra-high collection efficiency for particulate matter, the Advanced Hybrid™ Filter removed those trace elements associated with the particulate matter at very high efficiencies as well. As measured at the stack, all trace elements, with the exception of mercury, were near or below detection limits.

Table 13. Elemental Analysis of Advanced Hybrid™ Pilot-Scale Hopper Ash, 100% PRB Coal

Date Sampled Oxide	11/18/02 %	11/19/02 %	11/20/02 %
SiO_2		20.9	
Al_2O_3		16.1	
Fe_2O_3		7.30	
CaO		34.8	
MgO		5.93	
Na_2O		3.14	
K_2O		0.80	
P_2O_5		2.87	
TiO_2		1.58	
BaO		1.18	
MnO		0.07	
SrO		0.53	
SO_3		4.83	
LOI	0.86	0.72	1.11
Cu, mg/kg		370	
V, mg/kg		300	
Zn, mg/kg		2170	